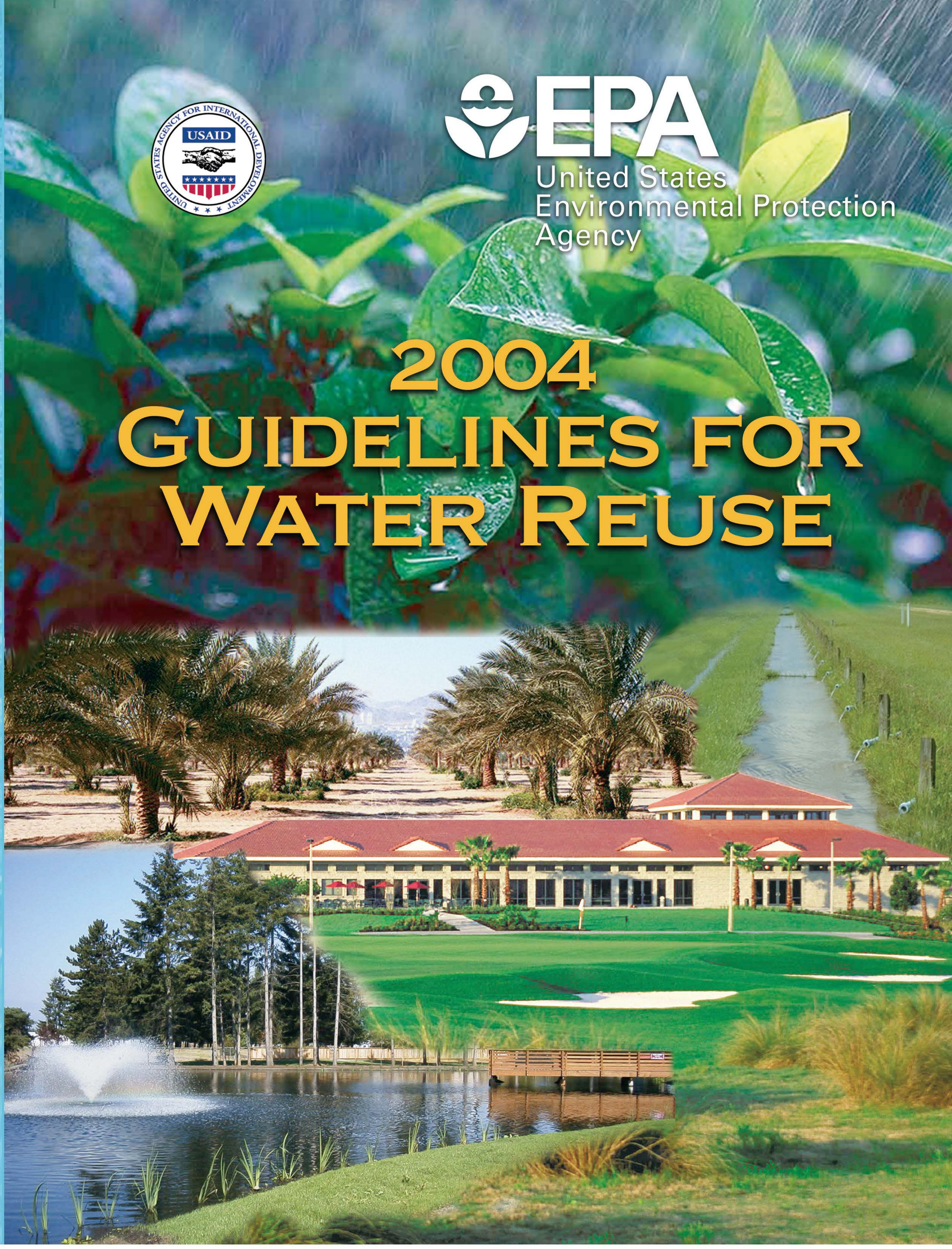

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
USAID

EPA
United States
Environmental Protection
Agency

2004
GUIDELINES FOR WATER REUSE

EPA/625/R-04/108
September 2004

Guidelines for Water Reuse

U.S. Environmental Protection Agency

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Notice

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Foreword

In an effort to help meet growing demands being placed on available water supplies, many communities throughout the U.S. and the world are turning to water reclamation and reuse. Water reclamation and reuse offer an effective means of conserving our limited high-quality freshwater supplies while helping to meet the ever growing demands for water.

For many years, effluent discharges have been accepted as an important source for maintaining minimum stream flows. The investment in treatment technologies required to meet restrictive discharge limits has lead an increasing number of industries and communities to consider other uses for their treated wastewater effluents as a means to recover at least a part of this investment. Further, as sources of water supplies have become limited, there has been greater use and acceptance of reclaimed wastewater effluents as an alternative source of water for a wide variety of applications, including landscape and agricultural irrigation, toilet and urinal flushing, industrial processing, power plant cooling, wetland habitat creation, restoration and maintenance, and groundwater recharge. In some areas of the country, water reuse and dual water systems with purple pipe for distribution of reclaimed water have become fully integrated into local water supplies.

The *2004 Guidelines for Water Reuse* examines opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. It presents and summarizes recommended water reuse guidelines, along with supporting information, as guidance for the benefit of the water and wastewater utilities and regulatory agencies, particularly in the U.S. The document updates the *1992 Guidelines* document by incorporating information on water reuse that has been developed since the 1992 document was issued. This revised edition also expands coverage of water reuse issues and practices in other countries. It includes many new and updated case studies, expanded coverage of indirect potable reuse and industrial reuse issues, new information on treatment and disinfection technologies, emerging chemicals and pathogens of concern, economics, user rates and funding alternatives, public involvement and acceptance (both successes and failures), research activities and results, and sources of further information. It also includes as an updated matrix of state regulations and guidelines, and a list of state contacts. This information should be useful to states in developing water reuse standards, and revising or expanding existing regulations. It should also be useful to planners, consulting engineers and others actively involved in the evaluation, planning, design, operation or maintenance of water reclamation and reuse facilities.

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Acknowledgements

The *Guidelines for Water Reuse* debuted in 1980 and was updated in 1992. Since then, water reuse practices have continued to develop and evolve. This edition of the Guidelines offers new information and greater detail about a wide range of reuse applications and introduces new health considerations and treatment technologies supporting water reuse operations. It includes an updated inventory of state reuse regulations and an expanded coverage of water reuse practices in countries outside of the U. S. Dozens of reuse experts contributed text and case studies to highlight how reuse applications can and do work in the real world.

The 2004 *Guidelines for Water Reuse* document was built upon information generated by the substantial research and development efforts and extensive demonstration projects on water reuse practices throughout the world, ranging from potable reuse to wetlands treatment. Some of the most useful sources drawn upon in developing this update include: proceedings from American Water Works Association/Water Environment Federal (AWWA/WEF) Water Reuse conferences, WEF national conferences, and WateReuse conferences; selected articles from WEF and AWWA journals; materials provided by the *Guidelines* review committee; and a series of WERF reports on water reclamation and related subjects published by the National Research Counsel/National Academy of Sciences, WEF/AWWA.

Please note that the statutes and regulations described in this document may contain legally binding requirements. The summaries of those laws provided here, as well as the approaches suggested in this document, do not substitute for those statutes or regulations, nor are these guidelines themselves any kind of regulation. This document is intended to be solely informational and does not impose legally-binding requirements on EPA, States, local or tribal governments, or members of the public. Any EPA decisions regarding a particular water reuse project will be made based on the applicable statutes and regulations. EPA will continue to review and update these guidelines as necessary and appropriate.

This version of the *Guidelines for Water Reuse* document was developed by Camp Dresser & McKee Inc. (CDM) through a Cooperative Research and Development Agreement (CRADA) with the U.S. Environmental Protection Agency (EPA) under the direction of Robert L. Matthews, P.E., DEE as Project Director and David K. Ammerman, P.E. as Project Manager, with hands-on assistance from Karen K. McCullen, P.E., Valerie P. Going, P.E., and Lisa M. Prieto, E.I. of CDM. These developers also wish to acknowledge the help of Dr. James Crook, P.E., Dr. Bahman Sheikh; Julia Forgas, Gloria Booth, and Karen Jones of CDM, as well as; MerriBeth Farnham of Farnham and Associates, Inc. and Perry Thompson of Thompson and Thompson Graphics Inc.

Partial funding to support the preparation of the updated *Guidelines* document was provided by EPA and the U.S. Agency for International Development (USAID). The *Guidelines* document was prepared by CDM with contributions from more 100 participants from other consulting firms, state and federal agencies, local water and wastewater authorities, and academic institutions. We wish to acknowledge the direction, advice, and suggestions of the sponsoring agencies, notably: Mr. Robert K. Bastian and Dr. John Cicmanec of EPA, as well as Dr. Peter McCornick, P.E., Dr. John Austin, and Mr. Dan Deely of USAID. We would also like to thank the many technical reviewers who so painstakingly reviewed this document.

Our special thanks go to the following group of our colleagues who took the time to share their life experiences and technical knowledge to make these *Guidelines* relevant and user-friendly. The contributors are broken up into three categories: those who directly authored and/or edited text, those who attended the technical review meeting (TRC), and those who were general reviewers. Some contributors are listed more than once to demonstrate their multiple roles in the preparation of the document.

Please note that the listing of these contributors in no way identifies them as supporters of this document or represents their ideas and/or opinions on the subject. These persons are the leaders in the field and their expertise from every angle has added to the depth and breadth of the document.

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CHAPTER 1

Introduction

The world's population is expected to increase dramatically between now and the year 2020 - and with this growth will come an increased need for water to meet various needs, as well as an increased production of wastewater. Many communities throughout the world are approaching, or have already reached, the limits of their available water supplies; water reclamation and reuse have almost become necessary for conserving and extending available water supplies. Water reuse may also present communities with an alternate wastewater disposal method as well as provide pollution abatement by diverting effluent discharge away from sensitive surface waters. Already accepted and endorsed by the public in many urban and agricultural areas, properly implemented nonpotable reuse projects can help communities meet water demand and supply challenges without any known significant health risks.

1.1 Objectives of the Guidelines

Water reclamation for nonpotable reuse has been adopted in the U.S. and elsewhere without the benefit of national or international guidelines or standards. Twenty-five states currently have regulations regarding water reuse. The World Health Organization (WHO) guidelines for agricultural irrigation reuse (dated 1989) are under revision (World Health Organization Website, 2003).

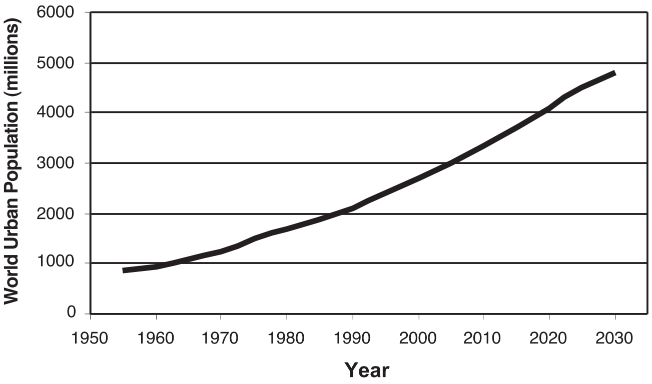
The primary purpose of the 2004 EPA *Guidelines for Water Reuse* is to present and summarize water reuse guidelines, with supporting information, for the benefit of utilities and regulatory agencies, particularly in the U.S. The *Guidelines* cover water reclamation for nonpotable urban, industrial, and agricultural reuse, as well as augmentation of potable water supplies through indirect reuse. Direct potable reuse is also covered, although only briefly since it is not practiced in the U.S. Please note that the statutes and regulations described in this document may contain legally binding requirements. The summaries of those laws provided here, as well as the approaches suggested in this document, do not substitute for those statutes or regulations, nor are these guidelines themselves any kind of regulation. In addition, neither the U.S. Environmental Protection Agency (EPA) nor the U.S. Agency for International Development (USAID) proposes standards for water reuse in this publication or any other. This document is intended to be solely informational and does not impose legally-binding requirements on EPA, states, local or tribal governments, or members of the public. Any EPA decisions regarding a particular water reuse project will be made based on the applicable statutes and regulations. EPA will continue to review and update these guidelines as necessary and appropriate.

In states where standards do not exist or are being revised or expanded, the *Guidelines* can assist in developing reuse programs and appropriate regulations. The *Guidelines* will also be useful to consulting engineers and others involved in the evaluation, planning, design, operation, or management of water reclamation and reuse facilities. In addition, an extensive chapter on international reuse is included to provide background information and discussion of relevant water reuse issues for authorities in other countries where reuse is being planned, developed, and implemented. In the U.S., water reclamation and reuse standards are the responsibility of state agencies.

1.2 Water Demands and Reuse

Growing urbanization in water-scarce areas of the world exacerbates the situation of increasing water demands for domestic, industrial, commercial, and agricultural purposes. **Figure 1-1** demonstrates the rapid growth rate of the urban population worldwide. In the year 2000, 2.85 billion people (out of a worldwide population of 6.06 billion) were living in urban regions (United Nations Secretariat, 2001). This increasing urban population results in a growing water demand to meet domestic, commercial, industrial, and agricultural needs. Coupled with depleting fresh water sources, utility directors and managers are faced with the challenge to supply water to a growing customer base.

Figure 1-1 Estimated and Projected Urban Population in the World



Adapted from: United Nations Secretariat, 2001.

The U.S. Bureau of Reclamation is developing a program, Water 2025, to focus attention on the emerging need for water. Explosive population growth in urban areas of the western U.S., along with a growing demand for available water supplies for environmental and recreational uses, is conflicting with the national dependence on water for the production of food and fiber from western farms and ranches (Department of the Interior/Bureau of Reclamation, 2003). The goals of Water 2025 are to:

- Facilitate a more forward-looking focus on water-starved areas of the country
- Help stretch or increase water supplies, satisfy the demands of growing populations, protect environmental needs, and strengthen regional, tribal, and local economies
- Provide added environmental benefits to many watersheds, rivers, and streams
- Minimize water crises in critical watersheds by improving the environment and addressing the effects of drought on important economies
- Provide a balanced, practical approach to water management for the next century

Meanwhile, water reuse in the U.S. is a large and growing practice. An estimated 1.7 billion gallons (6.4 million m^3) per day of wastewater is reused, and reclaimed water use on a volume basis is growing at an estimated 15 percent per year. In 2002, Florida reclaimed 584 mgd (2.2×10^6 m^3) of its wastewater while California ranked a close second, with an estimated total of 525 mgd (2.0×10^6 m^3) of reclaimed water used each day. Florida has an official goal of reclaiming 1 billion gallons per day by the year 2010. Likewise, California has a statutory goal of doubling its current use by 2010. Texas currently reuses approximately 230 mgd (8.7×10^5 m^3) and Arizona reuses an estimated 200 mgd (7.6×10^5 m^3). While these 4 states account for the majority of the water reuse in the U.S., several other states have growing water reuse programs including Nevada, Colorado, Georgia, North Carolina, Virginia, and Washington. At least 27 states now have water reclamation facilities, and the majority of states have regulations dealing with water reuse (Gritzuk, 2003).

1.3 Source Substitution

Under the broad definition of water reclamation and reuse, sources of reclaimed water may range from industrial process waters to the tail waters of agricultural irrigation systems. For the purposes of these *Guidelines*, however, the sources of reclaimed water are limited to the effluent generated by domestic wastewater treatment facilities (WWTFs).

The use of reclaimed water for nonpotable purposes offers the potential for exploiting a “new” resource that can be substituted for existing potable sources. This idea, known as “source substitution” is not new. In fact, the United Nations Economic and Social Council enunciated a policy in 1958 that, “No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade.” Many urban, commercial, and industrial uses can be met with water of less than potable water quality. With respect to potable water sources, EPA policy states, “Because of human frailties associated with protection, priority should be given to selection of the purest source” (EPA, 1976). Therefore, when the demand exceeds the capacity of the purest source, and additional sources are unavailable or available only at a high cost, lower quality water can be substituted to serve the nonpotable purposes. Since few areas enjoy a surplus of high quality water, and demand often exceeds capacity, many urban residential, commercial, and industrial uses can be satisfied with water of less than potable water quality. In many instances, treated wastewater may provide the most economical and/or available substitute source for such uses as irrigation of lawns, parks, roadway borders, and medians; air conditioning and industrial cooling towers; stack gas scrubbing; industrial processing; toilet flushing; dust control and construction; cleaning and maintenance, including vehicle washing; scenic waters and fountains; and environmental and recreational purposes.

The economics of source substitution with reclaimed water are site-specific and dependent on the marginal costs of new sources of high-quality water and the costs of wastewater treatment and disposal. Understandably, the construction of reclaimed water transmission and distribution lines to existing users in large cities is expensive and disruptive. As a result, wastewater reclamation and reuse will continue to be most attractive in serving new residential, commercial, and industrial areas of a city, where the installation of dual distribution systems would be far more economical than in already developed areas.

Use of reclaimed water for agricultural purposes near urban areas can also be economically attractive. Agricultural users are usually willing to make long-term commitments, often for as long as 20 years, to use large quantities of reclaimed water instead of fresh water sources. One potential scenario is to develop a new reclaimed water system to serve agricultural needs outside the city with the expectation that when urban development replaces agricultural lands in time, reclaimed water use can be shifted from agricultural to new urban development.

1.4 Pollution Abatement

While the need for additional water supply in arid and semi-arid areas has been the impetus for numerous water reclamation and reuse programs, many programs in the U.S. were initiated in response to rigorous and costly requirements to remove nitrogen and phosphorus for effluent discharge to surface waters. By eliminating effluent discharges for all or even a portion of the year through water reuse, a municipality may be able to avoid or reduce the need for the costly nutrient removal treatment processes. For example, the South Bay Water Recycling Project in San Jose, California, provides reclaimed water to 1.3 million area residents. By reusing this water instead of releasing it to the San Francisco Bay, San Jose has avoided a sewer moratorium that would have had a devastating impact on the Silicon Valley economy (Gritzuk, 2003).

The purposes and practices may differ between water reuse programs developed strictly for pollution abatement and those developed for water resources or conservation benefits. When systems are developed chiefly for the purpose of land treatment or disposal, the objective is to treat and/or dispose of as much effluent on as little land as possible; thus, application rates are often greater than irrigation demands. On the other hand, when the reclaimed water is considered a valuable resource (i.e., an alternative water supply), the objective is to apply the water according to irrigation needs.

Differences are also apparent in the distribution of reclaimed water for these different purposes. Where disposal is the objective, meters are difficult to justify, and reclaimed water is often distributed at a flat rate or at minimal cost to the users. However, where reclaimed water is intended to be used as a water resource, metering is appropriate to provide an equitable method for distributing the resource, limiting overuse, and recovering costs. In St. Petersburg, Florida, disposal was the original objective; however, over time the reclaimed water became an important resource. Meters, which were not provided initially, are being considered to prevent wasting of the reclaimed water.

1.5 Treatment and Water Quality Considerations

Water reclamation and nonpotable reuse typically require conventional water and wastewater treatment technologies that are already widely practiced and readily available in many countries throughout the world. When discussing treatment for a reuse system, the overriding concern continues to be whether the quality of the reclaimed water is appropriate for the intended use. Higher level uses, such as irrigation of public-access lands or vegetables to be consumed without processing, require a higher level of wastewater treatment and reliability prior to reuse than will lower level uses, such as irrigation of forage crops and pasture. For example, in urban settings, where there is a high potential for human exposure to reclaimed water used for landscape irrigation, industrial purposes, and toilet flushing, the reclaimed water must be clear, colorless, and odorless to ensure that it is aesthetically acceptable to the users and the public at large, as well as to assure minimum health risk. Experience has shown that facilities producing secondary effluent can become water reclamation plants with the addition of filtration and enhanced disinfection processes.

A majority of the states have published treatment standards or guidelines for one or more types of water reuse. Some of these states require specific treatment processes; others impose effluent quality criteria, and some require both. Many states also include requirements for treatment reliability to prevent the distribution of any reclaimed water that may not be adequately treated because of a process upset, power outage, or equipment failure. Dual distribution systems (i.e., reclaimed water distribution systems that parallel a potable water system) must also incorporate safeguards to prevent cross-connections of reclaimed water and potable water lines and the misuse of reclaimed water. For example, piping, valves, and hydrants are marked or color-coded (e.g. purple pipe) to differentiate reclaimed water from potable water. Backflow prevention devices are installed, and hose bibs on reclaimed water lines may be prohibited to preclude the likelihood of incidental human misuse. A strict industrial pretreatment program is also necessary to ensure the reliability of the biological treatment process by excluding the discharge of potentially toxic levels of pollutants to the sanitary sewer system. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

1.6 Overview of the Guidelines

This document, the *Guidelines for Water Reuse,* is an update of the *Guidelines for Water Reuse* developed for EPA by Camp Dresser & McKee Inc. (CDM) and published by EPA in 1992 (and initially in 1980). In May 2002, EPA contracted with CDM through a Cooperative Research and Development Agreement (CRADA) to update the EPA/USAID *Guidelines for Water Reuse* (EPA/625/R-92/004: Sept 1992). As with the 1992 *Guidelines*, a committee, made up of national and international experts in the field of water reclamation and related subjects, was established to develop new text, update case studies, and review interim drafts of the document. However, unlike the 1992 version, the author and reviewer base was greatly expanded to include approximately 75 contributing authors and an additional 50 reviewers. Major efforts associated with the revisions to this edition of the *Guidelines* include:

- Updating the state reuse regulations matrix and adding a list of state contacts
- Updating U.S. Geological Survey (USGS) information on national water use and reuse practices
- Expanding coverage of indirect potable reuse issues, emphasizing the results of recent studies and practices associated with using reclaimed water to augment potable supplies
- Expanding coverage of industrial reuse issues
- Expanding coverage of reuse projects and practices outside of the U.S
- Adding more case studies to illustrate experience in all areas of water reclamation
- Expanding the discussion of health issues to include emerging chemicals and pathogens
- Updating the discussion of treatment technologies applicable to water reclamation
- Updating information on economics, user rates, and project funding mechanisms

The document has been arranged by topic, devoting separate chapters to each of the key technical, financial, legal and institutional, and public involvement issues that a reuse planner might face. A separate chapter has also been provided to discuss reuse applications outside of the U.S. These chapters are:

- **Chapter 2, Types of Reuse Applications** – A discussion of reuse for urban, industrial, agricultural, recreational and habitat restoration/enhancement, groundwater recharge, and augmentation of potable supplies. Direct potable reuse is also briefly discussed.
- **Chapter 3, Technical Issues in Planning Water Reuse Systems –** An overview of the potential uses of reclaimed water, the sources of reclaimed water, treatment requirements, seasonal storage requirements, supplemental system facilities (including conveyance and distribution), operational storage, and alternative disposal systems.
- **Chapter 4, Water Reuse Regulations and Guidelines in the U.S.** – A summary of existing state standards and regulations as well as recommended guidelines.
- **Chapter 5, Legal and Institutional Issues** – An overview of reuse ordinances, user agreements, water rights, franchise law, and case law.
- **Chapter 6, Funding Water Reuse Systems** – A discussion of funding and cost recovery options for reuse system construction and operation, as well as management issues for utilities.
- **Chapter 7, Public Involvement Programs** – An outline of strategies for educating and involving the public in water reuse system planning and reclaimed water use.
- **Chapter 8, Water Reuse Outside the U.S.** – A summary of the issues facing reuse planners outside of the U.S., as well as a comprehensive review of the variety of reuse projects and systems around the world.

1.7 References

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CHAPTER 2

Types of Reuse Applications

Chapter 2 provides detailed explanations of major reuse application types. These include:

- Urban
- Industrial
- Agricultural
- Environmental and recreational
- Groundwater recharge
- Augmentation of potable supplies

Quantity and quality requirements are considered for each reuse application, as well as any special considerations necessary when reclaimed water is substituted for more traditional sources of water. Case studies of reuse applications are provided in Section 2.7. Key elements of water reuse that are common to most projects (i.e., supply and demand, treatment requirements, storage, and distribution) are discussed in Chapter 3.

2.1 Urban Reuse

Urban reuse systems provide reclaimed water for various nonpotable purposes including:

- Irrigation of public parks and recreation centers, athletic fields, school yards and playing fields, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities
- Irrigation of landscaped areas surrounding single-family and multi-family residences, general wash down, and other maintenance activities
- Irrigation of landscaped areas surrounding commercial, office, and industrial developments
- Irrigation of golf courses
- Commercial uses such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides, herbicides, and liquid fertilizers
- Ornamental landscape uses and decorative water features, such as fountains, reflecting pools, and waterfalls
- Dust control and concrete production for construction projects
- Fire protection through reclaimed water fire hydrants
- Toilet and urinal flushing in commercial and industrial buildings

Urban reuse can include systems serving large users. Examples include parks, playgrounds, athletic fields, highway medians, golf courses, and recreational facilities. In addition, reuse systems can supply major water-using industries or industrial complexes as well as a combination of residential, industrial, and commercial properties through “dual distribution systems.” A 2-year field demonstration/research garden compared the impacts of irrigation with reclaimed versus potable water for landscape plants, soils, and irrigation components. The comparison showed few significant differences; however, landscape plants grew faster with reclaimed water (Lindsey *et al.,* 1996). But such results are not a given. Elevated chlorides in the reclaimed water provided by the City of St. Petersburg have limited the foliage that can be irrigated (Johnson, 1998).

In dual distribution systems, the reclaimed water is delivered to customers through a parallel network of distribution mains separate from the community’s potable water distribution system. The reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained, and managed in a manner similar to the potable water system. One of the oldest municipal dual distribution systems in the U.S., in St. Petersburg, Florida, has been in operation since 1977. The system provides reclaimed water for a mix of residential properties, commercial developments, industrial parks, a resource recovery power plant, a baseball stadium, and schools. The City of Pomona, California, first began distributing reclaimed water in 1973 to California Polytechnic University and has since added 2 paper mills, roadway landscaping, a regional park and a landfill with an energy recovery facility.

During the planning of an urban reuse system, a community must decide whether or not the reclaimed water system will be interruptible. Generally, unless reclaimed water is used as the only source of fire protection in a community, an interruptible source of reclaimed water is acceptable. For example, the City of St. Petersburg, Florida, decided that an interruptible source of reclaimed water would be acceptable, and that reclaimed water would provide backup only for fire protection.

If a community determines that a non-interruptible source of reclaimed water is needed, then reliability, equal to that of a potable water system, must be provided to ensure a continuous flow of reclaimed water. This reliability could be ensured through a municipality having more than one water reclamation plant to supply the reclaimed water system, as well as additional storage to provide reclaimed water in the case of a plant upset. However, providing the reliability to produce a non-interruptible supply of reclaimed water will have an associated cost increase. In some cases, such as the City of Burbank, California, reclaimed water storage tanks are the only source of water serving an isolated fire system that is kept separate from the potable fire service.

Retrofitting a developed urban area with a reclaimed water distribution system can be expensive. In some cases, however, the benefits of conserving potable water may justify the cost. For example, a water reuse system may be cost-effective if the reclaimed water system eliminates or forestalls the need to:

- Obtain additional water supplies from considerable distances
- Treat a raw water supply source of poor quality (e.g., seawater desalination)
- Treat wastewater to stricter surface water discharge requirements

In developing urban areas, substantial cost savings may be realized by installing a dual distribution system as developments are constructed. A successful way to accomplish this is to stipulate that connecting to the system is a requirement of the community's land development code. In 1984, the City of Altamonte Springs, Florida, enacted the requirement for developers to install reclaimed water lines so that all properties within a development are provided service. This section of the City's land development code also stated, "The intent of the reclaimed water system is not to duplicate the potable water system, but rather to complement each other and thereby provide the opportunity to reduce line sizes and looping requirements of the potable water system" (Howard, Needles, Tammen, and Bergendoff, 1986a).

The Irvine Ranch Water District in California studied the economic feasibility of expanding its urban dual distribution system to provide reclaimed water to high-rise buildings for toilet and urinal flushing. The study concluded that the use of reclaimed water was feasible for flushing toilets and urinals and priming floor drain traps for buildings of 6 stories and higher (Young and Holliman, 1990). Following this study, an ordinance was enacted requiring all new buildings over 55 feet (17 meters) high to install a dual distribution system for flushing in areas where reclaimed water is available (Irvine Ranch Water District, 1990).

The City of Avalon, California, conducted a feasibility study to assess the replacement of seawater with reclaimed water in the City's nonpotable toilet flushing/fire protection distribution system. The study determined that the City would save several thousand dollars per year in amortized capital and operation and maintenance costs by switching to reclaimed water (Richardson, 1998).

2.1.1 Reclaimed Water Demand

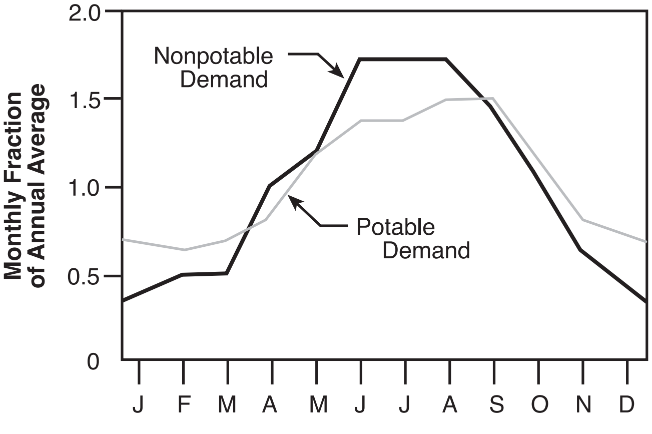
The daily irrigation demand for reclaimed water generated by a particular urban system can be estimated from an inventory of the total irrigable acreage to be served by the reclaimed water system and the estimated weekly irrigation rates. These rates are determined by such factors as local soil characteristics, climatic conditions, and type of landscaping. In some states, recommended weekly irrigation rates may be available from water management agencies, county or state agricultural agents, or irrigation specialists. Reclaimed water demand estimates must also take into account any other permitted uses for reclaimed water within the system.

An estimate of the daily irrigation demand for reclaimed water can also be made by evaluating local water billing records. For example, in many locations, second water meters measure the volume of potable water used outside the home, primarily for irrigation. An evaluation of the water billing records in Orlando, Florida, showed the average irrigation demand measured on the residential second meter was approximately 506 gpd (1.9 m^3/d), compared to 350 gpd (1.3 m^3/d) on the first meter, which measured the amount of water for in-house use (CDM, 2001). This data indicates that a 59 percent reduction in residential potable water demand could be accomplished if a dual distribution system were to provide irrigation service.

Water use records can also be used to estimate the seasonal variation in reclaimed water demand. **Figure 2-1** and **Figure 2-2** show the historic monthly variation in the potable and nonpotable water demand for the Irvine Ranch Water District in California and St. Petersburg, Florida, respectively. Although the seasonal variation in demand is different between the 2 communities, both show a similar trend in the seasonal variation between potable and nonpotable demand. Even though St. Petersburg and Irvine Ranch meet much of the demand for irrigation with reclaimed water, the influence of these uses can still be seen in the potable water demands.

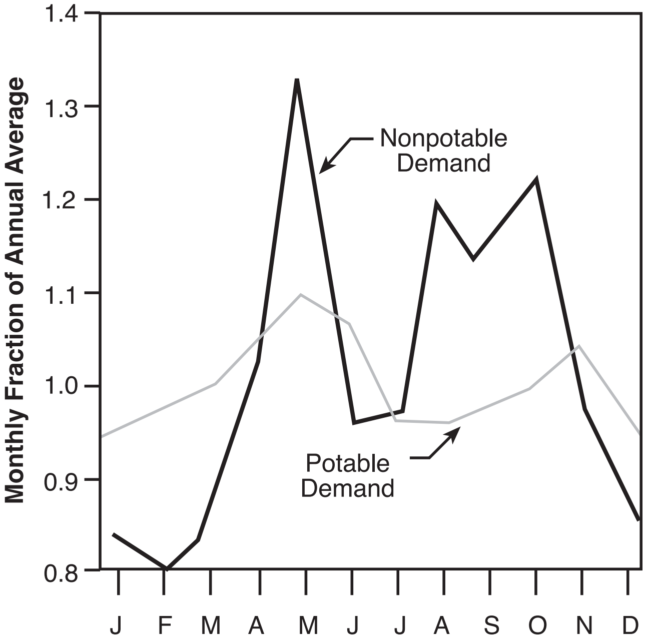
For potential reclaimed water users, such as golf courses, that draw irrigation water from onsite wells, an evaluation of the permitted withdrawal rates or pumping records can be used to estimate their reclaimed water needs.

Figure 2-1. Potable and Nonpotable Water Use - Monthly Historic Demand Variation, Irvine Ranch Water District, California



In assessing the reuse needs of an urban system, demands for uses other than irrigation must also be considered. These demands are likely to include industrial, commercial, and recreational uses. Demands for industrial users, as well as commercial users, such as car washes, can be estimated from water use or billing records. Demands for recreational impoundments can be estimated by determining the volume of water required to maintain a desired water elevation in the impoundment.

Figure 2-2. Potable and Nonpotable Water Use - Monthly Historic Demand Variation, St. Petersburg, Florida



For those systems using reclaimed water for toilet flushing as part of their urban reuse system, water use records can again be used to estimate demand. According to Grisham and Fleming (1989), toilet flushing can account for up to 45 percent of indoor residential water demand. In 1991, the Irvine Ranch Water District began using reclaimed water for toilet flushing in high-rise office buildings. Potable water demands in these buildings have decreased by as much as 75 percent due to the reclaimed water use (IRWD, 2003).

2.1.2 Reliability and Public Health Protection

In the design of an urban reclaimed water distribution system, the most important considerations are the reliability of service and protection of public health. Treatment to meet appropriate water quality and quantity requirements and system reliability are addressed in Section 3.4. The following safeguards must be considered during the design of any dual distribution system:

- Assurance that the reclaimed water delivered to the customer meets the water quality requirements for the intended uses

- Prevention of improper operation of the system

- Prevention of cross-connections with potable water lines

- Prevention of improper use of nonpotable water

To avoid cross connections, all above-ground appurtenances and equipment associated with reclaimed water systems must be clearly marked. National color standards have not been established, but most manufacturers, counties, and cities have adopted the color purple for reclaimed water lines. The State of Florida has accepted Pantone 522C as the color of choice for reclaimed water material designation. Florida also requires signs to be posted with specific language in both English and Spanish identifying the resource as nonpotable. Additional designations include using the international symbol for "Do Not Drink" on all materials, both surface and subsurface, to minimize potential cross connections. A more detailed discussion of distribution safeguards and cross connection control measures is presented in Section 3.6.1, Conveyance and Distribution Facilities.

2.1.3 Design Considerations

Urban water reuse systems have 2 major components:

1. Water reclamation facilities

2. Reclaimed water distribution system, including storage and pumping facilities

2.1.3.1 Water Reclamation Facilities

Water reclamation facilities must provide the required treatment to meet appropriate water quality standards for the intended use. In addition to secondary treatment, filtration, and disinfection are generally required for reuse in an urban setting. Because urban reuse usually involves irrigation of properties with unrestricted public access or other types of reuse where human exposure to the reclaimed water is likely, reclaimed water must be of a higher quality than may be necessary for other reuse applications. In cases where a single large customer needs a higher quality reclaimed water, the customer may have to provide additional treatment onsite, as is commonly done with potable water. Treatment requirements are presented in Section 3.4.2.

2.1.3.2 Distribution System

Reclaimed water operational storage and high-service pumping facilities are usually located onsite at the water reclamation facility. However, in some cases, particularly for large cities, operational storage facilities may be located at appropriate locations in the system and/or near the reuse sites. When located near the pumping facilities, ground or elevated tanks may be used; when located within the system, operational storage is generally elevated.

Sufficient storage to accommodate diurnal flow variation is essential to the operation of a reclaimed water system. The volume of storage required can be determined from the daily reclaimed water demand and supply curves. Reclaimed water is normally produced 24 hours per day in accordance with the diurnal flow at the water reclamation plant and may flow to ground storage to be pumped into the system or into a clear well for high-lift pumping to elevated storage facilities. In order to maintain suitable water quality, covered storage is preferred to preclude biological growth and maintain chlorine residual. Refer to Section 3.5.2 for a discussion of operational storage.

Since variations in the demand for reclaimed water occur seasonally, large volumes of seasonal storage may be needed if all available reclaimed water is to be used, although this may not be economically practical. The selected location of a seasonal storage facility will also have an effect on the design of the distribution system. In areas where surface storage may be limited due to space limitations, aquifer storage and recovery (ASR) could prove to be a viable enhancement to the system. Hillsborough County, Florida has recovered ASR water, placed it into the reuse distribution system, and is working to achieve a target storage volume of 90 million gallons (340,700 m^3) (McNeal, 2002). A detailed discussion of seasonal storage requirements is provided in Section 3.5.

The design of an urban distribution system is similar in many respects to a municipal potable water distribution system. Materials of equal quality for construction are recommended. System integrity should be assured; however, the reliability of the system need not be as stringent as a potable water system unless reclaimed water is being used as the only source of fire protection. No special measures are required to pump, deliver, and use the water. No modifications are required because reclaimed water is being used, with the exception that equipment and materials must be clearly identified. For service lines in urban settings, different materials may be desirable for more certain identification.

The design of distribution facilities is based on topographical conditions as well as reclaimed water demand requirements. If topography has wide variations, multilevel systems may have to be used. Distribution mains must be sized to provide the peak hourly demands at a pressure adequate for the user being served. Pressure requirements for a dual distribution system vary depending on the type of user being served. Pressures for irrigation systems can be as low as 10 psi (70 kPa) if additional booster pumps are provided at the point of delivery, and maximum pressures can be as high as 100 to 150 psi (700 to 1,000 kPa).

The peak hourly rate of use, which is a critical consideration in sizing the delivery pumps and distribution mains, may best be determined by observing and studying local urban practices and considering time of day and rates of use by large users to be served by the system. The following design peak factors have been used in designing urban reuse systems:

System	Peaking Factor
Altamonte Springs, Florida (HNTB, 1986a)	2.90
Apopka, Florida (Godlewski *et al.*, 1990)	4.00
Aurora, Colorado (Johns *et al.*, 1987)	2.50
Boca Raton, Florida (CDM, 1990a)	2.00
Irvine Ranch Water District, California (IRWD, 1991)	
- Landscape Irrigation	6.80
- Golf Course and Agricultural Irrigation	2.00
San Antonio Water System (SAWS), Texas (SAWS Website, 2004)	1.92
Sea Pines, South Carolina (Hirsekorn and Ellison, 1987)	2.00
St. Petersburg, Florida (CDM, 1987)	2.25

The wide range of peaking factors reflects the nature of the demands being served, the location of the reuse system (particularly where irrigation is the end use), and the experience of the design engineers. San Antonio's low peaking factor was achieved by requiring onsite storage for customer demands greater than 100 acre-feet per year (62 gpm). These large customers were allowed to receive a peak flow rate based on a 24-hour delivery of their peak month demand in July. This flat rate delivery and number of large irrigation customers resulted in a low system peaking factor.

For reclaimed water systems that include fire protection as part of their service, fire flow plus the maximum daily demand should be considered when sizing the distribution system. This scenario is not as critical in sizing the delivery pumps since it will likely result in less pumping capacity, but is critical in sizing the distribution mains because fire flow could be required at any point in the system, resulting in high localized flows.

The Irvine Ranch Water District Water Resources Master Plan recommends a peak hourly use factor of 6.8 when reclaimed water is used for landscape irrigation and a peak factor of 2.0 for agricultural and golf course irrigation systems (IRWD, 1991). The peak factor for landscape irrigation is higher because reclaimed water use is restricted to between 9 p.m. and 6 a.m. This restriction may not apply to agricultural or golf course use.

Generally, there will be "high-pressure" and "low-pressure" users on an urban reuse system. The high-pressure users receive water directly from the system at pressures suitable for the particular type of reuse. Examples include residential and landscape irrigation, industrial processes and cooling water, car washes, fire protection, and toilet flushing in commercial and industrial buildings. The low-pressure users receive reclaimed water into an onsite storage pond to be repumped into their reuse system. Typical low-pressure users are golf courses, parks, and condominium developments that use reclaimed water for irrigation. Other low-pressure uses include the delivery of reclaimed water to landscape or recreational impoundments, or industrial or cooling tower sites that have onsite tanks for blending and/or storing water.

Typically, urban dual distribution systems operate at a minimum pressure of 50 psi (350 kPa), which will satisfy the pressure requirements for irrigation of larger landscaped areas such as multi-family complexes, and offices, commercial, and industrial parks. A minimum pressure of 50 psi (350 kPa) should also satisfy the requirements of car washes, toilet flushing, construction dust control, and some industrial uses. Based on requirements of typical residential irrigation equipment, a minimum delivery pressure of 30 psi (210 kPa) is used for the satisfactory operation of in-ground residential irrigation systems.

For users who operate at higher pressures than other users on the system, additional onsite pumping will be required to satisfy the pressure requirements. For example, golf course irrigation systems typically operate at higher pressures (100 to 200 psi or 700 kPa to 1,400 kPa), and if directly connected to the reclaimed water system, will likely require a booster pump station. Repumping may be required in high-rise office buildings using reclaimed water for toilet flushing. Additionally, some industrial users may operate at higher pressures.

The design of a reuse transmission system is usually accomplished through the use of computer modeling, with portions of each of the sub-area distribution systems representing demand nodes in the model. The demand of each node is determined from the irrigable acreage tributary to the node, the irrigation rate, and the daily irrigation time period. Additional demands for uses other than irrigation, such as fire flow protection, toilet flushing, and industrial uses must also be added to the appropriate node.

The 2 most common methods of maintaining system pressure under widely varying flow rates are: (1) constant-speed supply pumps and system elevated storage tanks, which maintain essentially consistent system pressures, or (2) constant-pressure, variable-speed, high-service supply pumps, which maintain a constant system pressure while meeting the varying demand for reclaimed water by varying the pump speed. While each of these systems has advantages and disadvantages, either system will perform well and remains a matter of local choice. The dual distribution system of the City of Altamonte Springs, Florida operates with constant-speed supply pumps and 2 elevated storage tanks, and pressures range between 55 and 60 psi (380 kPa and 410 kPa). The urban system of the Marin Municipal Water District, in California, operates at a system pressure of 50 to 130 psi (350 kPa and 900 kPa), depending upon elevation and distance from the point of supply, while Apopka, Florida operates its reuse system at a pressure of 60 psi (410 kPa).

The system should be designed with the flexibility to institute some form of usage control when necessary and provide for the potential resulting increase in the peak hourly demand. One such form of usage control would be to vary the days per week that schools, parks, golf courses, and residential areas are irrigated. In addition, large users, such as golf courses, will have a major impact on the shape of the reclaimed water daily demand curve, and hence on the peak hourly demand, depending upon how the water is delivered to them. The reclaimed water daily demand curve may be "flattened" and the peak hourly demand reduced if the reclaimed water is discharged to golf course ponds over a 24-hour period or during the daytime hours when demand for residential landscape irrigation is low. These methods of operation can reduce peak demands, thereby reducing storage requirements, pumping capacities, and pipe diameters. This in turn, can reduce construction cost.

2.1.4 Using Reclaimed Water for Fire Protection

Reclaimed water may be used for fire protection, but this application requires additional design efforts (Snyder *et al*., 2002). Urban potable water distribution systems are typically sized based on fire flow requirements. In residential areas, this can result in 6-inch diameter pipes to support fire demands where 2-inch diameter pipes may be sufficient to meet potable needs. Fire flow requirements also increase the volume of water required to be in storage at any given time. While this results in a very robust distribution system, the increased pipe size and storage required for fire flows results in increased residence time within the distribution system, and a corresponding potential reduction in reclaimed water quality. In Rouse Hill, an independent community near Sydney, Australia, reclaimed water lines are being sized to handle fire flows, allowing potable line sizes to be reduced. Due to a shortage of potable water supplies, the City of Cape Coral, Florida, designed a dual distribution system supplied by reclaimed water and surface water that provides for fire protection and urban irrigation. This practice was possible due to the fact that nonpotable service, including the use of reclaimed water for fire protection, was part of the planning of the development before construction. However, these benefits come at the cost of elevating the reclaimed water system to an essential service with reliability equal to that of the potable water system. This in turn, requires redundancy and emergency power with an associated increase in cost. For these reasons, the City has decided to not include fire protection in its future reclaimed water distribution systems. This decision was largely based on the fact that the inclusion of fire protection limited operations of the reclaimed water distribution system. Specifically, the limited operations included the lack of ability to reduce the operating pressure and to close valves in the distribution system.

In some cases, municipalities may be faced with replacing existing potable water distribution systems, because the pipe material is contributing to water quality problems. In such instances, consideration could be given to converting the existing network into a nonpotable distribution system capable of providing fire protection and installing a new, smaller network to handle potable demands. Such an approach would require a comprehensive cross connection control process to ensure all connections between the potable and nonpotable system were severed. Color-coding of below-ground piping also poses a challenge. To date, no community has attempted such a conversion. More often, the primary means of fire protection is the potable water system, with reclaimed water systems providing an additional source of water for fire flows. In the City of St. Petersburg, Florida, fire protection is shared between potable and reclaimed water. In San Francisco, California, reclaimed water is part of a dual system for fire protection that includes high-rise buildings. Reclaimed water is also available for fire protection in the Irvine Ranch Water District, California. In some cases, site-specific investigations may determine that reclaimed water is the most cost-effective means of providing fire protection. The City of Livermore, California, determined that using reclaimed water for fire protection at airport hangers and a wholesale warehouse store would be less expensive than upgrading the potable water system (Johnson and Crook, 1998).

2.2 Industrial Reuse

Industrial reuse has increased substantially since the early 1990s for many of the same reasons urban reuse has gained popularity, including water shortages and increased populations, particularly in drought areas, and legislation regarding water conservation and environmental compliance. To meet this increased demand, many states have increased the availability of reclaimed water to industries and have installed the necessary reclaimed water distribution lines. As a result, California, Arizona, Texas, Florida, and Nevada have major industrial facilities using reclaimed water for cooling water and process/boiler-feed requirements. Utility power plants are ideal facilities for reuse due to their large water requirements for cooling, ash sluicing, rad-waste dilution, and flue gas scrubber requirements. Petroleum refineries, chemical plants, and metal working facilities are among other industrial facilities benefiting from reclaimed water not only for cooling, but for process needs as well.

2.2.1 Cooling Water

For the majority of industries, cooling water is the largest use of reclaimed water because advancements in water treatment technologies have allowed industries to successfully use lesser quality waters. These advancements have enabled better control of deposits, corrosion, and biological problems often associated with the use of reclaimed water in a concentrated cooling water system.

There are 2 basic types of cooling water systems that use reclaimed water: (1) once-through and (2) recirculating evaporative. The recirculating evaporative cooling water system is the most common reclaimed water system due to its large water use and consumption by evaporation.

2.2.1.1 Once-Through Cooling Water Systems

As implied by the name, once-through cooling water systems involve a simple pass of cooling water through heat exchangers. There is no evaporation, and therefore, no consumption or concentration of the cooling water. Very few once-through cooling systems use reclaimed water and, in most instances, are confined to locations where reuse is convenient, such as where industries are located near an outfall. For example, Bethlehem Steel Company in Baltimore, Maryland, has used 100 mgd (4,380 l/s) of treated wastewater effluent from Baltimore's Back River Wastewater Treatment Facility for processes and once-through cooling water system since the early 1970s. The Rawhide Energy Station utility power plant in Fort Collins, Colorado, has used about 245 mgd (10,753 l/s) of reclaimed water for once through cooling of condensers since the 1980s. The reclaimed water is added to a body of water and the combined water is used in the once-through cooling system. After one-time use, the water is returned to the original water source (lake or river).

2.2.1.2 Recirculating Evaporative Cooling Water Systems

Recirculating evaporative cooling water systems use water to absorb process heat, and then transfer the heat by evaporation. As the cooling water is recirculated, makeup water is required to replace water lost through evaporation. Water must also be periodically removed from the cooling water system to prevent a buildup of dissolved solids in the cooling water. There are 2 common types of evaporative cooling systems that use reclaimed water: (1) cooling towers and (2) spray ponds.

2.2.1.2a Cooling Tower Systems

Like all recirculating evaporative systems, cooling water towers are designed to take advantage of the absorption and transfer of heat through evaporation. Over the past 10 years, cooling towers have increased in efficiency so that only 1.75 percent of the recirculated water is evaporated for every 10 °F (6 °C) drop in process water heat, decreasing the need to supplement with makeup water. Because water is evaporated, the dissolved solids and minerals will remain in the recirculated water. These solids must be removed or treated to prevent accumulation on the cooling equipment as well as the cooling tower. This removal is accomplished by discharging a portion of the cooling water, referred to as blow-down water. The blow-down water is usually treated by a chemical process and/or a filtration/softening/clarification process before disposal. Buildup of total dissolved solids can occur within the reclamation/industrial cooling system if the blow-down waste stream, with increased dissolved solids, is recirculated between the water reclamation plant and the cooling system.

The Curtis Stanton Energy Facility in Orlando, Florida, receives reclaimed water from an Orange County wastewater facility for cooling water. Initially, the blow-down water was planned to be returned to the wastewater facility. However, this process would eventually increase the concentration of dissolved solids in the reclaimed water to a degree that it could not be used as cooling water in the future. So, as an alternative, the blow-down water is crystallized at the Curtis Stanton facility and disposed of at a landfill. The City of San Marcos, Texas, identified the following indirect impacts associated with receiving the blow-down water back at their wastewater treatment plant: reduced treatment capacity, impact to the biological process, and impact to the plant effluent receiving stream (Longoria *et al.,* 2000). To avoid the impacts to the wastewater treatment plant, the City installed a dedicated line to return the blow-down water directly to the UV disinfection chamber. Therefore, there was no loss of plant capacity or impact to the biological process. The City has provided increased monitoring of the effluent-receiving stream to identify any potential stream impacts.

Cooling tower designs vary widely. Large hyperbolic concrete structures, as shown in **Figure 2-3**, range from 250 to 400 feet (76 to 122 meters) tall and 150 to 200 feet (46 to 61 meters) in diameter, and are common at utility power plants. These cooling towers can recirculate approximately 200,000 to 500,000 gpm (12,600 to 31,500 l/s) of water and evaporate approximately 6,000 to 15,000 gpm (380 to 950 l/s) of water.

Smaller cooling towers can be rectangular boxes constructed of wood, concrete, plastic, and/or fiberglass reinforced plastic with circular fan housings for each cell. Each cell can recirculate (cool) approximately 3,000 to 5,000 gpm (190 to 315 l/s). Petroleum refineries, chemical plants, steel mills, smaller utility plants, and other processing industries can have as many as 15 cells in a single cooling tower, recirculating approximately 75,000 gpm (4,700 l/s). Commercial air conditioning cooling tower systems can recirculate as little as 100 gpm (6 l/s) to as much as 40,000 gpm (2,500 l/s).

The cycles of concentration (COC) are defined as the ratio of a given ion or compound in the cooling tower water compared to the identical ion or compound in the makeup water. For example, if the sodium chloride level in the cooling tower water is 200 mg/l, and the same compound in the makeup water is 50 mg/l, then the COC is 200 divided by 50, or 4, often referred to as 4 cycles. Industries often operate their cooling towers at widely different cycles of concentration as shown in **Table 2-1**. The reason for such variations is that the cooling water is used for different applications such as wash water, ash sluicing, process water, etc.

2.2.1.2b Spray Ponds

Spray ponds are usually small lakes or bodies of water where warmed cooling water is directed to nozzles that

Table 2-1. Typical Cycles of Concentration (COC)

Industry	Typical COC
Utilities	
Fossil	5-8
Nuclear	6-10
Petroleum Refineries	6-8
Chemical Plants	8-10
Steel Mills	3-5
HVAC	3-5
Paper Mills	5-8

Figure 2-3. Cooling Tower

spray upward to mix with air. This spraying causes evaporation, but usually only produces a 3 to 8 ° F drop in temperature. Spray ponds are often used by facilities, such as utility power plants, where minimal cooling is needed and where the pond can also be incorporated into either decorative fountains or the air conditioning system. Reclaimed water has some application related to spray ponds, usually as makeup water, since there are often restrictions on discharging reclaimed water into lakes or ponds. In addition, there is a potential for foaming within the spray pond if only reclaimed water is used. For example, the City of Ft. Collins, Colorado, supplies reclaimed water to the Platte River Power Authority for cooling its 250 megawatt (MW) Rawhide Energy Station. The recirculation cooling system is a 5.2-billion-gallon (20-million-m^3) lake used to supply 170,000 gpm (107,000 l/s) to the condenser and auxiliary heat exchangers. Reclaimed water is treated to reduce phosphate and other contaminants, and then added to the freshwater lake.

2.2.1.3 Cooling Water Quality Requirements

The most frequent water quality problems in cooling water systems are corrosion, biological growth, and scaling. These problems arise from contaminants in potable water as well as in reclaimed water, but the concentrations of some contaminants in reclaimed water may be higher than in potable water. **Table 2-2** provides some reclaimed water quality data from Florida and California.

In Burbank, California, about 5 mgd (219 l/s) of municipal secondary effluent has been successfully utilized for cooling water makeup in the City's power generating plant since 1967. The reclaimed water is of such good quality that with the addition of chlorine, acid, and corrosion inhibitors, the reclaimed water quality is nearly equal to that of freshwater. There are also numerous petroleum refineries in the Los Angeles area in California that have used reclaimed water since 1998 as 100 percent of the makeup water for their cooling systems.

The City of Las Vegas and Clark County Sanitation District uses 90 mgd (3,940 l/s) of secondary effluent to supply 35 percent of the water demand in power generating stations operated by the Nevada Power Company. The power company provides additional treatment consisting of 2-stage lime softening, filtration, and chlorination prior to use as cooling tower makeup. A reclaimed water reservoir provides backup for the water supply. The Arizona Public Service 1,270-MW Palo Verde nuclear power plant is located 55 miles from Phoenix, Arizona, and uses almost all of the City of Phoenix and area cities' reclaimed water at an average rate of 38,000 gpm (2,400 l/s).

In a partnership between the King County Department of Metropolitan Services (Seattle, Washington), the Boeing Company, and Puget Sound Power and Light Company, a new 600,000-square-foot (55,740-m^2) Customer Service Training Center is cooled using chlorinated secondary effluent (Lundt, 1996).

In Texas, The San Antonio Water System (SAWS) has a provision in its service agreement that allows for adjustment in the reclaimed water rates for cooling tower use if the use of reclaimed water results in fewer cycles of concentration.

2.2.1.3a Corrosion Concerns

The use of any water, including reclaimed water, as makeup in recirculating cooling tower systems will result in the concentration of dissolved solids in the heat exchange system. This concentration may or may not cause serious corrosion of components. Three requirements should be considered to identify the cooling system corrosion potential:

1. Calculation of the concentrated cooling water quality – most often "worst" case but also "average expected" water quality

Table 2-2. Florida and California Reclaimed Water Quality

Water Constituents	Orlando	Tampa	Los Angeles	San Francisco
Conductivity	1200 – 1800	600 – 1500	2000 – 2700	800 – 1200
Calcium Hardness	180 – 200	100 – 120	260 – 450	50 – 180
Total Alkalinity	150 – 200	60 – 100	140 – 280	30 – 120
Chlorides	20 – 40	30 – 80	250 – 350	40 – 200
Phosphate	18 – 25	10 – 20	300 – 400	20 – 70
Ammonia	10 – 15	5 – 15	4 – 20	2 – 8
Suspended Solids	3 – 5	3 – 5	10 – 45	2 – 10

2. Identification of metal alloys in the process equipment that will contact cooling water– primarily heat exchanger/cooler/condenser tubing but also all other metals in the system, including lines, water box, tube sheet, and cooling tower

3. Operating conditions (temperatures and water flow) of the cooling tower – primarily related to the heat exchanger tubing but also the other metals in the system

Depending upon its level of treatment, the quality of reclaimed water can vary substantially. The amount of concentration in the cooling system will also vary substantially, depending on the cycles of concentration within the system. Certainly, any contamination of the cooling water through process in-leakage, atmospheric conditions, or treatment chemicals will impact the water quality.

2.2.1.3b Biological Concerns

Biological concerns associated with the use of reclaimed water in cooling systems include:

- Microbiological organisms that contribute to the potential for deposits and microbiologically induced corrosion (MIC)
- Nutrients that contribute to microbiological growth

Microbiological organisms (bacteria, fungus, or algae) that contribute to deposits and corrosion are most often those adhering to surfaces and identified as “sessile” microorganisms. The deposits usually occur in low flow areas (2 feet per second [0.6 m/s] or less) but can stick to surfaces even at much greater flow rates (5 to 8 feet per second [1.5 to 2 m/s]). The deposits can create a variety of concerns and problems. Deposits can interfere with heat transfer and can cause corrosion directly due to acid or corrosive by-products. Indirectly, deposits may shield metal surfaces from water treatment corrosion inhibitors and establish under-deposit corrosion. Deposits can grow rapidly and plug heat exchangers, cooling tower film fill, or cooling tower water distribution nozzles/sprays.

Reclaimed water generally has a very low level of microbiological organisms due to the treatment requirements prior to discharge. Chlorine levels of 2.0 mg/l (as free chlorine) will kill most sessile microorganisms that cause corrosion or deposits in cooling systems.

Nutrients that contribute to microbiological growth are present in varying concentrations in reclaimed water. However, even when freshwater is used in cooling towers, chemicals added during the treatment process can contribute a considerable concentration of nutrients. It is also important to have a good biological control program in place before reclaimed water is used. Ammonia and organics are typical nutrients found in reclaimed water that can reduce or negate some commonly used biocides (particularly cationic charged polymers).

2.2.1.3c Scaling Concerns

The primary constituents for scale potential from reclaimed water are calcium, magnesium, sulfate, alkalinity, phosphate, silica, and fluoride.

Combinations of these minerals that can produce scale in the concentrated cooling water generally include calcium phosphate (most common), silica (fairly common), calcium sulfate (fairly common), calcium carbonate (seldom found), calcium fluoride (seldom found), and magnesium silicate (seldom found).

All constituents with the potential to form scale must be evaluated and controlled by chemical treatment and/or by adjusting the cycles of concentration. Reclaimed water quality must be evaluated, along with the scaling potential to establish the use of specific scale inhibitors. Guidelines for selection and use of scale inhibitors are available as are scale predictive tools.

2.2.2 Boiler Make-up Water

The use of reclaimed water for boiler make-up water differs little from the use of conventional public water supply; both require extensive additional treatment. Quality requirements for boiler make-up water depend on the pressure at which the boiler is operated. Generally, the higher the pressure, the higher the quality of water required. Very high pressure (1500 psi [10,340 kPa] and above) boilers require make-up water of very high quality.

In general, both potable water and reclaimed water used for boiler water make-up must be treated to reduce the hardness of the boiler feed water to close to zero. Removal or control of insoluble scales of calcium and magnesium, and control of silica and alumina, are required since these are the principal causes of scale buildup in boilers. Depending on the characteristics of the reclaimed water, lime treatment (including flocculation, sedimentation, and recarbonation) might be followed by multi-media filtration, carbon adsorption, and nitrogen removal. High-purity boiler feed water for high-pressure boilers might also require treatment by reverse osmosis or ion exchange. High alkalinity may contribute to foaming, resulting in deposits in the superheater, reheater, or turbines. Bicarbonate alkalinity, under the influence of boiler heat, may lead to the release of carbon dioxide, which is a source of corrosion in steam-using equipment. The considerable treatment and relatively small amounts of make-up water required normally make boiler make-up water a poor candidate for reclaimed water.

Since mid-2000, several refineries located in southern Los Angeles, California, have used reclaimed water as their primary source of boiler make-up water. Through the use of clarification, filtration, and reverse osmosis, high-quality boiler make-up water is produced that provides freshwater, chemical, and energy savings. The East Bay Municipal Utility District in California provides reclaimed water to the Chevron Refinery for use as boiler feed water. **Table 2-3** shows the sampling requirements and expected water quality for the reclaimed water.

2.2.3 Industrial Process Water

The suitability of reclaimed water for use in industrial processes depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components. On the other hand, the tanning industry can use relatively low-quality water. Requirements for textiles, pulp and paper, and metal fabricating are intermediate. Thus, in investigating the feasibility of industrial reuse with reclaimed water, potential users must be contacted to determine the specific requirements for their process water.

A full-scale demonstration plant, operated at Toppan Electronics, in San Diego, California, has shown that reclaimed water can be used for the production of circuit boards (Gagliardo *et al.,* 2002). The reclaimed water used for the demonstration plant was pretreated with microfiltration. **Table 2-4** presents industrial process water quality requirements for a variety of industries.

2.2.3.1 Pulp and Paper Industry

The historical approach of the pulp and paper industry has been to internally recycle water to a very high degree. The pulp and paper industry has long recognized the potential benefits associated with water reuse. At the turn of the century, when the paper machine was being developed, water use was approximately 150,000 gallons per ton (625 liters per kilogram). By the 1950s, the water usage rate was down to 35,000 gallons per ton (145 liters per kilogram) (Wyvill *et al*., 1984). An industry survey conducted in 1966 showed the total water use for a bleached Kraft mill to be 179,000 gallons per ton (750 liters per kilogram) (Haynes, 1974). Modern mills approach a recycle ratio of 100 percent, using only 16,000 to 17,000 gallons of freshwater per ton (67 to 71 liters per kilogram) (NCASI, 2003).

About a dozen pulp and paper mills use reclaimed water. Less than half of these mills use treated municipal wastewater. Tertiary treatment is generally required. The driver is usually an insufficient source of freshwater. SAPPI's Enstra mill in South Africa has been using treated municipal wastewater since the early 1940s. In Lake Tahoe, California, the opportunities for using treated wastewater in pulping and papermaking arose with the construction of tertiary wastewater facilities (Dorica *et al.*,1998).

Some of the reasons that mills choose not to use treated municipal wastewater include:

- Concerns about pathogens
- Product quality requirements that specifically preclude its use
- Possibly prohibitive conveyance costs
- Concerns about potentially increased corrosion, scaling, and biofouling problems due to the high degree of internal recycling involved

Table 2-5 shows the water quality requirements for several pulp and paper processes in New York City.

2.2.3.2 Chemical Industry

The water quality requirements for the chemical industry vary greatly according to production requirements. Generally, waters in the neutral pH range (6.2 to 8.3) that are also moderately soft with low turbidity, suspended solids (SS), and silica are required; dissolved solids and chloride content are generally not critical (Water Pollution Control Federation, 1989).

2.2.3.3 Textile Industry

Waters used in textile manufacturing must be non-staining; hence, they must be low in turbidity, color, iron, and manganese. Hardness may cause curds to deposit on the textiles and may cause problems in some of the processes that use soap. Nitrates and nitrites may cause problems in dyeing.

In 1997, a local carpet manufacturer in Irvine, California, retrofitted carpet-dyeing facilities to use reclaimed water year-round (IRWD, 2003). The new process is as effective as earlier methods and is saving up to 500,000 gallons of potable water per day (22 l/s).

Table 2-3. North Richmond Water Reclamation Plant Sampling Requirements

Location[1]	Sample Type	Parameter	Frequency	Target Value[2]
Samples Required for Compliance with RWQCB Order 90-137				
Chevron Tie-In	Grab	Turbidity, Total Chlorine Residual[1], Total Coliform[2]	Daily	Max. 2 NTU, Min. 300 CT, 2.2 MPN/100 ml
Reclaimed Water Effluent	24-hour composite[3]	Flow	Continuous	NA
Samples Required for Compliance with EBMUD-Chevron Agreement; Chevron's NPDES Permit				
Filter Influent, Filter Effluent, Chlorine Contact Basin Effluent	Online Analyzers[3]	pH, Turbidity, Free Chlorine Residual	Continuous	6.5-7.5, 2 NTU, <4.0 mg/l
Reclaimed Water Effluent	24-hour composite	Orthophosphate (PO$_4$)	Daily	<1.4 mg/l
Reclaimed Water Effluent	24-hour composite	Calcium, Total Iron, Magnesium, Silica, TSS Ammonia (NH$_3$-N), Chloride	Daily	50 mg/l, 0.1 mg/l, 20 mg/l, 10 mg/l, <1.0 mg/l, <175 mg/l
Reclaimed Water Effluent	96-hour flow through	Rainbow trout acute bioassay	Weekly	>90% Survival
Reclaimed Water Effluent	24-hour composite	COD, TOC (Grab), Selenium, Surfactants	Weekly	<50 mg/l, Report Only <1.0 mg/l
Reclaimed Water Effluent	24-hour composite	Total Chromium, Hexavalent Cr, Ag, As, TOC, Cd, Cyanide, Cu, Hg, Pb, Ni, Zn – mg/▯	Monthly	Report Only[4]
Reclaimed Water Effluent	24-hour composite	Total Phenolics, PAHs	Quarterly	Report Only[4]
Reclaimed Water Effluent	Grab	Oil and Grease, Total Sulfides	Quarterly	Report Only[4]
Reclaimed Water Effluent	Grab	Volatile Organics, Halogenated Volatile Organics	Twice/Year	Report Only[4]
Reclaimed Water Effluent	Grab	TCDD Equivalents, Tributyltin, Halogenated Volatile Organics, Polychlorinated Biphenyls, Pesticides	Once/Year	Report Only[4]

NOTES:

1. Chlorine residual may vary based on CT calculation (contact time x residual = 300 CT); 90 minute minimum contact time.
2. Sample must be collected at reclaimed water metering station at pipeline tie-in to Chevron Refinery cooling towers; 90 minute chlorine contact time requirement.
3. Readouts for online analyzers are on graphic panel in Operations Center.
4. "Report Only" parameters are used for pass-through credit for reclaimed water constituents as provided for in Chevron's National Pollutant Discharge Elimination System (NPDES) permit.

Source: Yologe, 1996

Table 2-4. Industrial Process Water Quality Requirements

Parameter*	Pulp & Paper			Chemical	Petrochem & Coal	Textiles		Cement
	Mechanical Piping	Chemical, Unbleached	Pulp & Paper Bleached			Sizing Suspension	Scouring, Bleach & Dye	
Cu	-	-	-	-	0.05	0.01	-	-
Fe	0.3	1.0	0.1	0.1	1.0	0.3	0.1	2.5
Mn	0.1	0.5	0.05	0.1	-	0.05	0.01	0.5
Ca	-	20	20	68	75	-	-	-
Mg	-	12	12	19	30	-	-	-
Cl	1,000	200	200	500	300	-	-	250
HCO_3	-	-	-	128	-	-	-	-
NO_3	-	-	-	5	-	-	-	-
SO_4	-	-	-	100	-	-	-	250
SiO_2	-	50	50	50	-	-	-	35
Hardness	-	100	100	250	350	25	25	-
Alkalinity	-	-	-	125	-	-	-	400
TDS	-	-	-	1,000	1,000	100	100	600
TSS	-	10	10	5	10	5	5	500
Color	30	30	10	20	-	5	5	-
pH	6-10	6-10	6-10	6.2-8.3	6-9	-	-	6.5-8.5
CCE	-	-	-	-	-	-	-	-

*All values in mg/l except color and pH.

Source: Water Pollution Control Federation, 1989.

Table 2-5. Pulp and Paper Process Water Quality Requirements

Parameter [(a)]	Mechanical Pulping	Chemical, Unbleached	Pulp and Paper, Bleached
Iron	0.3	1	0.1
Manganese	0.1	0.5	0.05
Calcium	-	20	20
Magnesium	-	12	12
Chlorine	1,000	200	200
Silicon Dioxide	-	50	50
Hardness	-	100	100
TSS	-	10	10
Color	30	30	10
pH	6 - 10	6 - 10	6 - 10

(a) All values in mg/l except color and pH.

Source: Adamski *et al.,* 2000

2.2.3.4 Petroleum and Coal

Processes for the manufacture of petroleum and coal products can usually tolerate water of relatively low quality. Waters generally must be in the 6 to 9 pH range and have moderate SS of no greater than 10 mg/l.

2.3 Agricultural Reuse

This section focuses on the following specific considerations for implementing a water reuse program for agricultural irrigation:

- Agricultural irrigation demands
- Reclaimed water quality
- Other system considerations

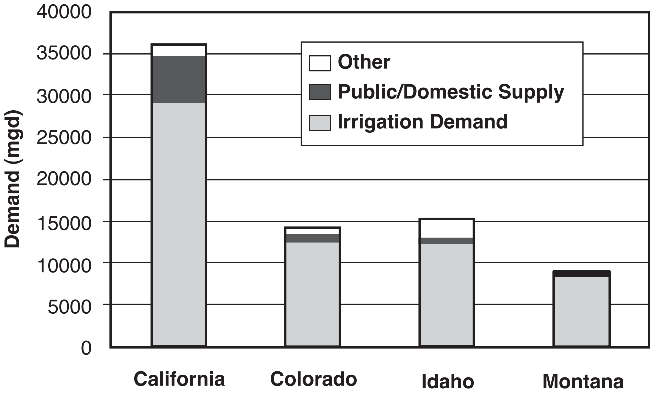
Technical issues common to all reuse programs are discussed in Chapter 3, and the reader is referred to the following subsections for this information: 3.4 – Treatment Requirements, 3.5 – Seasonal Storage Requirements, 3.6 – Supplemental Facilities (conveyance and distribution, operational storage, and alternative disposal).

Agricultural irrigation represents a significant percentage of the total demand for freshwater. As discussed in Chapter 3, agricultural irrigation is estimated to represent 40 percent of the total water demand nationwide (Solley *et al*., 1998). In western states with significant agricultural production, the percentage of freshwater used for irrigation is markedly greater. For example, **Figure 2-4** illustrates the total daily freshwater withdrawals, public water supply, and agricultural irrigation usage for Montana, Colorado, Idaho, and California. These states are the top 4 consumers of water for agricultural irrigation, which accounts for more than 80 percent of their total water demand.

The total cropland area in the U.S. and Puerto Rico is estimated to be approximately 431 million acres (174 million hectares), of which approximately 55 million acres (22 million hectares) are irrigated. Worldwide, it is estimated that irrigation water demands exceed all other categories of water use and make up 75 percent of the total water usage (Solley *et al.,* 1998).

A significant portion of existing water reuse systems supply reclaimed water for agricultural irrigation. In Florida, agricultural irrigation accounts for approximately 19 percent of the total volume of reclaimed water used within the state (Florida Department of Environmental Protection, 2002b). In California, agricultural irrigation accounts for approximately 48 percent of the total volume of reclaimed water used within the state (California State Water Resources Control Board, 2002). **Figure 2-5** shows the percentages of the types of crops irrigated with reclaimed water in California.

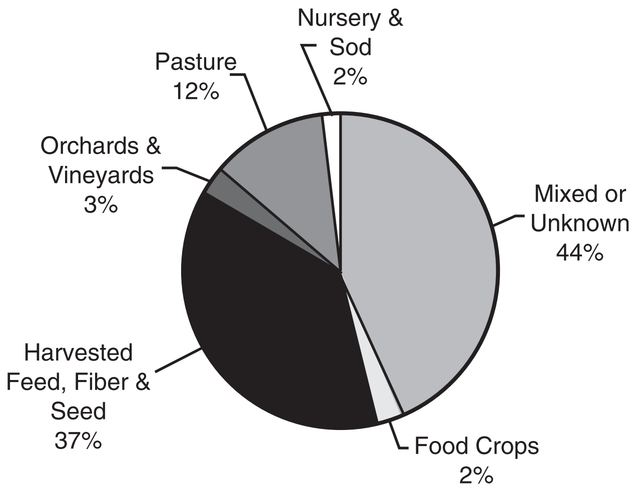
Figure 2-4. Comparison of Agricultural Irrigation, Public/Domestic, and Total Freshwater Withdrawals



Agricultural reuse is often included as a component in water reuse programs for the following reasons:

- Extremely high water demands for agricultural irrigation

Figure 2-5. Agricultural Reuse Categories by Percent in California



Source: California State Water Control Board, 2000

- Significant water conservation benefits associated with reuse in agriculture

- Ability to integrate agricultural reuse with other reuse applications

Due to saltwater intrusion to its agricultural wells, the City of Watsonville, California, is looking to develop 4,000 acre-feet per year (2,480 gpm) of reuse for the irrigation of strawberries, artichokes, and potentially certified organic crops (Raines *et al.,* 2002). Reclaimed water will make up 25 percent of the estimated new water required for irrigation.

2.3.1 Estimating Agricultural Irrigation Demands

Because crop water requirements vary with climatic conditions, the need for supplemental irrigation will vary from month to month throughout the year. This seasonal variation is a function of rainfall, temperature, crop type, stage of plant growth, and other factors, depending on the method of irrigation being used.

The supplier of reclaimed water must be able to quantify these seasonal demands, as well as any fluctuation in the reclaimed water supply, to assure that the demand for irrigation water can be met. Unfortunately, many agricultural users are unable to provide sufficient detail about irrigation demands for design purposes. This is because the user's seasonal or annual water use is seldom measured and recorded, even on land surfaces where water has been used for irrigation for a number of years. However, expert guidance is usually available through state colleges and universities and the local soil conservation service office.

To assess the feasibility of reuse, the reclaimed water supplier must be able to reasonably estimate irrigation demands and reclaimed water supplies. To make this assessment in the absence of actual water use data, evapotranspiration, percolation and runoff losses, and net irrigation must be estimated, often through the use of predictive equations.

2.3.1.1 Evapotranspiration

Evapotranspiration is defined as water either evaporated from the soil surface or actively transpired from the crop. While the concept of evapotranspiration is easily described, quantifying the term mathematically is difficult. Evaporation from the soil surface is a function of the soil moisture content at or near the surface. As the top layer of soil dries, evaporation decreases. Transpiration, the water vapor released through the plants' surface membranes, is a function of available soil moisture, season, and stage of growth. The rate of transpiration may be further impacted by soil structure and the salt concentration in the soil water. Primary factors affecting evaporation and transpiration are relative humidity, wind, and solar radiation.

Practically every state in the U.S. and Canada now has access to weather information from the Internet. California has developed the California Irrigation Management Information System (CIMIS), which allows growers to obtain daily reference evapotranspiration information. Data are made available for numerous locations within the state according to regions of similar climatic conditions. State publications provide coefficients for converting these reference data for use on specific crops, location, and stages of growth. This allows users to refine irrigation scheduling and conserve water. Other examples of weather networks are the Michigan State University Agricultural Weather Station, the Florida Automated Weather Network, and the Agri-Food Canada Lethbridge Research Centre Weather Station Network.

Numerous equations and methods have been developed to define the evapotranspiration term. The Thornthwaite and Blaney-Criddle methods of estimating evapotranspiration are 2 of the most cited methods. The Blaney-Criddle equation uses percent of daylight hours per month and average monthly temperature. The Thornthwaite method relies on mean monthly temperature and daytime hours. In addition to specific empirical equations, it is quite common to encounter modifications to empirical equations for use under specific regional conditions. In selecting an empirical method of estimating evapotranspiration, the potential user is encouraged to solicit input from local agencies familiar with this subject.

2.3.1.2 Effective Precipitation, Percolation, and Surface Water Runoff Losses

The approach for the beneficial reuse of reclaimed water will, in most cases, vary significantly from land application. In the case of beneficial reuse, the reclaimed water is a resource to be used judiciously. The prudent allocation of this resource becomes even more critical in locations where reclaimed water is assigned a dollar value, thereby becoming a commodity. Where there is a cost associated with using reclaimed water, the recipient of reclaimed water will seek to balance the cost of supplemental irrigation against the expected increase in crop yields to derive the maximum economic benefit. Thus, percolation losses will be minimized because they represent the loss of water available to the crop and wash fertilizers out of the root zone. An exception to this occurs when the reclaimed water has a high salt concentration and excess application is required to prevent the accumulation of salts in the root zone.

Irrigation demand is the amount of water required to meet the needs of the crop and also overcome system losses. System losses will consist of percolation, surface water runoff, and transmission and distribution losses. In addition to the above losses, the application of water to crops will include evaporative losses or losses due to wind drift. These losses may be difficult to quantify individually and are often estimated as single system efficiency. The actual efficiency of a given system will be site specific and vary widely depending on management practices followed. Irrigation efficiencies typically range from 40 to 98 percent (Vickers, 2001). A general range of efficiencies by type of irrigation system is shown in **Table 2-6**.

Since there are no hard and fast rules for selecting the most appropriate method for projecting irrigation demands and establishing parameters for system reliability, it may be prudent to undertake several of the techniques and to verify calculated values with available records. In the interest of developing the most useful models, local irrigation specialists should be consulted.

2.3.2 Reclaimed Water Quality

The chemical constituents in reclaimed water of concern for agricultural irrigation are salinity, sodium, trace elements, excessive chlorine residual, and nutrients. Sensitivity is generally a function of a given plant's tolerance to constituents encountered in the root zone or deposited on the foliage. Reclaimed water tends to have higher concentrations of these constituents than the groundwater or surface water sources from which the water supply is drawn.

The types and concentrations of constituents in reclaimed wastewater depend upon the municipal water supply, the influent waste streams (i.e., domestic and industrial contributions), amount and composition of infiltration in the wastewater collection system, the wastewater treatment processes, and type of storage facilities. Conditions that can have an adverse impact on reclaimed water quality may include:

- Elevated TDS levels
- Industrial discharges of potentially toxic compounds into the municipal sewer system
- Saltwater (chlorides) infiltration into the sewer system in coastal areas

Table 2-6. Efficiencies for Different Irrigation Systems

Irrigation System	Potential On-Farm Efficiency[1] (Percent)
Gravity (Surface)	
Improved gravity[2]	75-85
Furrow	55-70
Flood	40-50
Sprinklers	
Low energy precision application (LEPA)	80-90
Center pivot[3]	70-85
Sideroll	60-80
Solid set	65-80
Hand-move	60-65
Big gun	60-65
Microirrigation	
Drip	80-95

[1] Efficiencies shown assume appropriate irrigation system selection, correct irrigation design, and proper management.

[2] Includes tailwater recovery, precision land leveling, and surge flow systems.

[3] Includes high- and low-pressure center pivot.

Source: Vickers, 2001.

For example, reclaimed water is used mostly for ridge and furrow irrigation at the High Hat Ranch in Sarasota, Florida, although a portion of the reclaimed water is used for citrus irrigation via microjet irrigation. To achieve successful operation of the microjet irrigation system, filters were installed to provide additional solids removal treatment to the reclaimed water used for citrus irrigation.

2.3.2.1 Salinity

Salinity is the single most important parameter in determining the suitability of the water to be used for irrigation. Salinity is determined by measuring the electrical conductivity (EC) and/or the total dissolved solids (TDS) in the water. Estimates indicate that 23 percent of irrigated farmland has been damaged by salt (Postel, 1999). The salinity tolerance of plants varies widely. Crops must be chosen carefully to ensure that they can tolerate the salinity of the irrigation water, and even then the soil must be properly drained and adequately leached to prevent salt build-up. Leaching is the deliberate over-application of irrigation water in excess of crop needs to establish a downward movement of water and salt away from the root zone.

The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which salts are removed by leaching. Salt accumulation can be especially detrimental during germination and when plants are young (seedlings). At this stage, damage can occur even with relatively low salt concentrations. Concerns with salinity relate to possible impacts to the following: the soil's osmotic potential, specific ion toxicity, and degradation of soil physical conditions. These conditions may result in reduced plant growth rates, reduced yields, and, in severe cases, total crop failure.

The concentration of specific ions may cause one or more of these trace elements to accumulate in the soil and in the plant. Long-term build-up may result in animal and human health hazards or phytotoxicity in plants. When irrigating with municipal reclaimed water, the ions of most concern are sodium, chloride, and boron. Household detergents are usually the source of boron and water softeners contribute sodium and chloride. Plants vary greatly in their sensitivity to specific ion toxicity. Toxicity is particularly detrimental when crops are irrigated with overhead sprinklers during periods of high temperature and low humidity. Highly saline water applied to the leaves results in direct absorption of sodium and/or chloride and can cause leaf injury.

Salinity reduces the water uptake in plants by lowering the osmotic potential of the soil. This, in turn, causes the plant to use a large portion of its available energy to adjust the salt concentration within its tissue in order to obtain adequate water. This results in less energy available for plants to grow. The problem is more severe in hot and dry climatic conditions because of increased water demands by plants and is even more severe when irrigation is inadequate.

One location where subsurface drainage is being evaluated is in California's San Joaquin Valley. The drainage management process is called "integrated on-farm drainage management" and involves reusing the drainage water and using it to irrigate more salt-tolerant crops. The final discharge water goes into solar evaporators that collect the dry agricultural salt.

Further complications of salinity problems can occur in geographic locations where the water table is high. A high water table can cause a possible upward flow of high salinity water into the root zone. Subsurface drainage offers a viable solution in these locations. Older clay tiles are often replaced with fabric-covered plastic pipe to prevent clogging. This subsurface drainage technique is one salinity-controlling process that requires significant changes in irrigation management. There are other techniques that require relatively minor changes including more frequent irrigation schedules, selection of more salt-tolerant crops, seed placement, additional leaching, bed forming, and pre-plant irrigation.

2.3.2.2 Sodium

The potential influence sodium may have on soil properties is indicated by the sodium-adsorption-ratio (SAR), which is based on the effect of exchangeable sodium on the physical condition of the soil. SAR expresses the concentration of sodium in water relative to calcium and magnesium. Excessive sodium in irrigation water (when sodium exceeds calcium by more than a 3:1 ratio) contributes to soil dispersion and structural breakdown, where the finer soil particles fill many of the smaller pore spaces, sealing the surface and greatly reducing water infiltration rates (AWWA, 1997). For reclaimed water, it is recommended that the calcium ion concentration in the SAR equation be adjusted for alkalinity to include a more correct estimate of calcium in the soil water following irrigation, specifically adj RNa. Note that the calculated adj RNa is to be substituted for the SAR value.

Sodium salts influence the exchangeable cation composition of the soil, which lowers the permeability and affects the tilth of the soil. This usually occurs within the first few inches of the soil and is related to high sodium or very low calcium content in the soil or irrigation water. Sodium hazard does not impair the uptake of water by plants but does impair the infiltration of water into the soil. The growth of plants is thus affected by an unavailability of soil water (Tanji, 1990). Calcium and magnesium act as stabilizing ions in contrast to the destabilizing ion, sodium, in regard to the soil structure. They offset the phenomena related to the distance of charge neutralization for soil particles caused by excess sodium. Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably. Leaching and dissolving the calcium from the soil is of little concern when irrigating with reclaimed water because it is usually high enough in salt and calcium. Reclaimed water, however, may be high in sodium relative to calcium and may cause soil permeability problems if not properly managed.

2.3.2.3 Trace Elements

The elements of greatest concern at elevated levels are cadmium, copper, molybdenum, nickel, and zinc. Nickel and zinc have visible adverse effects in plants at lower concentrations than the levels harmful to animals and humans. Zinc and nickel toxicity is reduced as pH increases. Cadmium, copper, and molybdenum, however, can be harmful to animals at concentrations too low to impact plants.

Copper is not toxic to monogastric animals, but may be toxic to ruminants. However, their tolerance to copper increases as available molybdenum increases. Molybdenum can also be toxic when available in the absence of copper. Cadmium is of particular concern as it can accumulate in the food chain. It does not adversely affect ruminants due to the small amounts they ingest. Most milk and beef products are also unaffected by livestock ingestion of cadmium because the cadmium is stored in the liver and kidneys of the animal, rather than the fat or muscle tissues.

In addition, it was found that the input of heavy metals from commercial chemical fertilizer impurities was far greater than that contributed by the reclaimed water (Engineering Science, 1987).

Table 2-7 shows EPA's recommended limits for constituents in irrigation water.

The recommended maximum concentrations for "long-term continuous use on all soils" are set conservatively to include sandy soils that have low capacity to leach (and so to sequester or remove) the element in question. These maxima are below the concentrations that produce toxicity when the most sensitive plants are grown in nutrient solutions or sand cultures to which the pollutant has been added. This does not mean that if the suggested limit is exceeded that phytotoxicity will occur. Most of the elements are readily fixed or tied up in soil and accumulate with time. Repeated applications in excess of suggested levels might induce phytotoxicity. The criteria for short-term use (up to 20 years) are recommended for fine-textured neutral and alkaline soils with high capacities to remove the different pollutant elements.

2.3.2.4 Chlorine Residual

Free chlorine residual at concentrations less than 1 mg/l usually poses no problem to plants. However, some sensitive crops may be damaged at levels as low as 0.05 mg/l. Some woody crops, however, may accumulate chlorine in the tissue to toxic levels. Excessive chlorine has a similar leaf-burning effect as sodium and chloride when sprayed directly on foliage. Chlorine at concentrations greater than 5 mg/l causes severe damage to most plants.

2.3.2.5 Nutrients

The nutrients most important to a crop's needs are nitrogen, phosphorus, potassium, zinc, boron, and sulfur. Reclaimed water usually contains enough of these nutrients to supply a large portion of a crop's needs.

The most beneficial nutrient is nitrogen. Both the concentration and form of nitrogen need to be considered in irrigation water. While excessive amounts of nitrogen stimulate vegetative growth in most crops, it may also delay maturity and reduce crop quality and quantity. The nitrogen in reclaimed water may not be present in concentrations great enough to produce satisfactory crop yields, and some supplemental fertilizer may be necessary. In addition, excessive nitrate in forages can cause an imbalance of nitrogen, potassium, and magnesium in grazing animals. This is a concern if the forage is used as a primary feed source for livestock; however, such high concentrations are usually not expected with municipal reclaimed water.

Soils in the western U.S. may contain enough potassium, while many sandy soils of the southern U.S. do not. In either case, the addition of potassium with reclaimed water has little effect on crops. Phosphorus contained in reclaimed water is usually at too low a level to meet a crop's needs. Yet, over time, it can build up in the soil and reduce the need for phosphorus supplementation. Excessive phosphorus levels do not appear to pose any problems to crops, but can be a problem in runoff to surface waters.

Table 2-7. Recommended Limits for Constituents in Reclaimed Water for Irrigation

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/L.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten, & Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

Constituent	Recommended Limit	Remarks
pH	6.0	Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500 - 2,000 mg/l	Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/l	Concentrations greater than 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

Source: Adapted from Rowe and Abdel-Magid, 1995.

Numerous site-specific studies have been conducted regarding the potential water quality concerns associated with reuse irrigation. The overall conclusions from the Monterey (California) Wastewater Reclamation Study for Agriculture (Jaques, 1997) are as follows:

- Irrigation with filtered effluent (FE) or Title-22 effluent (T-22) appears to be as safe as well water.

- Few statistically significant differences were found in soil or plant parameters, and none were found to be attributable to different types of water. None of the differences had important implications for public health.

- Yields of annual crops were often significantly higher with reclaimed water.

- No viruses were detected in any of the reclaimed waters, although viruses were often detected in the secondary effluent prior to the reclamation process.

- The T-22 process was somewhat more efficient than the FE process in removing viruses when the influent was seeded at high levels of virus concentration. However, both processes demonstrated the ability to remove more than 5 logs of viruses during the seeding experiments. (Jaques, 1997)

This and other investigations suggest that reclaimed water is suitable for most agricultural irrigation needs.

2.3.3 Other System Considerations

In addition to irrigation supply and demand and reclaimed water quality requirements, there are other considerations specific to agricultural water reuse that must be addressed. Both the user and supplier of reclaimed water may have to consider modifications in current practice that may be required to use reclaimed water for agricultural irrigation. The extent to which current irrigation practices must be modified to make beneficial use of reclaimed water will vary on a case-by-case basis. Important considerations include:

- System reliability
- Site use control
- Monitoring requirements
- Runoff controls
- Marketing incentives
- Irrigation equipment

2.3.3.1 System Reliability

System reliability involves 2 basic issues. First, as in any reuse project that is implemented to reduce or eliminate surface water discharge, the treatment and distribution facilities must operate reliably to meet permit conditions. Second, the supply of reclaimed water to the agricultural user must be reliable in quality and quantity for successful use in a farming operation.

Reliability in quality involves providing the appropriate treatment for the intended use, with special consideration of crop sensitivities and potential toxicity effects of reclaimed water constituents (See Sections 3.4 and 2.3.2). Reliability in quantity involves balancing irrigation supply with demand. This is largely accomplished by providing sufficient operational and seasonal storage facilities (See Sections 3.5 and 3.5.2.) It is also necessary to ensure that the irrigation system itself can reliably accept the intended supply to minimize the need for discharge or alternate disposal.

2.3.3.2 Site Use Control

Many states require a buffer zone around areas irrigated with reclaimed water. The size of this buffer zone is often associated with the level of treatment the reclaimed water has received and the means of application. Additional controls may include restrictions on the times that irrigation can take place and restrictions on the access to the irrigated site. Such use area controls may require modification to existing farm practices and limit the use of reclaimed water to areas where required buffer zones cannot be provided. See Chapter 4 for a discussion of the different buffer zones and use controls specified in state regulations. Signs specifying that reclaimed water is being used may be required to prevent accidental contact or ingestion.

2.3.3.3 Monitoring Requirements

Monitoring requirements for reclaimed water use in agriculture differ by state (See Chapter 4). In most cases, the supplier will be required to sample the reclaimed water quality at specific intervals for specific constituents. Sampling may be required at the water reclamation plant and, in some cases, in the distribution system.

Groundwater monitoring is often required at the agricultural site, with the extent depending on the reclaimed water quality and the hydrogeology of the site. Groundwater monitoring programs may be as simple as a series of surficial wells to a complex arrangement of wells sampling at various depths. Monitoring must be considered in estimating the capital and operating costs of the reuse system, and a complete understanding of monitoring requirements is needed as part of any cost/benefit analysis.

2.3.3.4 Runoff Controls

Some irrigation practices, such as flood irrigation, result in a discharge of irrigation water from the site (tail water). Regulatory restrictions of this discharge may be few or none when using surface water or groundwater sources;

however, when reclaimed water is used, runoff controls may be required to prevent discharge or a National Pollutant Discharge Elimination System (NPDES) permit may be required for a surface water discharge.

2.3.3.5 Marketing Incentives

In many cases, an existing agricultural site will have an established source of irrigation water, which has been developed by the user at some expense (e.g., engineering, permitting, and construction). In some instances, the user may be reluctant to abandon these facilities for the opportunity to use reclaimed water. Reclaimed water use must then be economically competitive with existing irrigation practices or must provide some other benefits. For example, in arid climates or drought conditions where potable irrigation is restricted for water conservation purposes, reclaimed water could be offered as a dependable source of irrigation. Reclaimed water may also be of better quality than that water currently available to the farmer, and the nutrients may provide some fertilizer benefit. In some instances, the supplier of reclaimed water may find it cost effective to subsidize reclaimed water rates to agricultural users if reuse is allowing the supplier to avoid higher treatment costs associated with alternative means of disposal.

2.3.3.6 Irrigation Equipment

By and large, few changes in equipment are required to use reclaimed water for agricultural irrigation. However, some irrigation systems do require special considerations.

Surface irrigation systems (ridge and furrow, graded borders) normally result in the discharge of a portion of the irrigation water from the site. Where reclaimed water discharge is not permitted, some method of tail water return or pump-back may be required.

In sprinkler systems, dissolved salts and particulate matter may cause clogging, depending on the concentration of these constituents as well as the nozzle size. Because water droplets or aerosols from sprinkler systems are subject to wind drift, the use of reclaimed water may necessitate the establishment of buffer zones around the irrigated area. In some types of systems (i.e., center pivots), the sprinkler nozzles may be dropped closer to the ground to reduce aerosol drift and thus minimize the buffer requirements. In addition, some regulatory agencies restrict the use of sprinkler irrigation for crops to be eaten raw, because it results in the direct contact of reclaimed water with the fruit.

When reclaimed water is used in a micro-irrigation system, a good filtration system is required to prevent complete or partial clogging of emitters. Close, regular inspections of emitters are required to detect emitter clogging. In-line filters of an 80 to 200 mesh are typically used to minimize clogging. In addition to clogging, biological growth within the transmission lines and at the emitter discharge may be increased by nutrients in the reclaimed water. Due to low volume application rates with micro-irrigation, salts may accumulate at the wetted perimeter of the plants and then be released at toxic levels to the crop when leached via rainfall.

2.4 Environmental and Recreational Reuse

Environmental reuse includes wetland enhancement and restoration, creation of wetlands to serve as wildlife habitat and refuges, and stream augmentation. Uses of reclaimed water for recreational purposes range from landscape impoundments, water hazards on golf courses, to full-scale development of water-based recreational impoundments, incidental contact (fishing and boating) and full body contact (swimming and wading). As with any form of reuse, the development of recreational and environmental water reuse projects will be a function of a water demand coupled with a cost-effective source of suitable quality reclaimed water.

As discussed in Chapter 4, many states have regulations that specifically address recreational and environmental uses of reclaimed water. For example, California's recommended treatment train for each type of recreational water reuse is linked to the degree of body contact in that use (that is, to what degree swimming and wading are likely). Secondary treatment and disinfection to 2.2 total coliforms/100 ml average is required for recreational water bodies where fishing, boating, and other non-body contact activities are permitted. For nonrestricted recreational use that includes wading and swimming, treatment of secondary effluent is to be followed by coagulation, filtration, and disinfection to achieve 2.2 total coliforms/100 ml and a maximum of 23 total coliforms/100 ml in any one sample taken during a 30-day period.

In California, approximately 10 percent (47.6 mgd) (2080 l/s) of the total reclaimed water use within the state was associated with recreational and environmental reuse in 2000 (California State Water Resources Control Board, 2002). In Florida, approximately 6 percent (35 mgd or 1530 l/s) of the reclaimed water currently produced is being used for environmental enhancements, all for wetland enhancement and restoration (Florida Department of Environmental Protection, 2002). In Florida, from 1986 to 2001, there was a 53 percent increase (18.5 mgd to 35 mgd or 810 l/s to 1530 l/s) in the reuse flow used for environmental enhancements (wetland enhancement and restoration).

Two examples of large-scale environmental and recreational reuse projects are the City of West Palm Beach, Florida, wetlands-based water reclamation project (see case study 2.7.17) and the Eastern Municipal Water District multipurpose constructed wetlands in Riverside County, California.

The remainder of this section provides an overview of the following environmental and recreational uses:

- Natural and man-made wetlands
- Recreational and aesthetic impoundments
- Stream augmentation

The objectives of these reuse projects are typically to create an environment in which wildlife can thrive and/or develop an area of enhanced recreational or aesthetic value to the community through the use of reclaimed water.

2.4.1 Natural and Man-made Wetlands

Over the past 200 years, approximately 50 percent of the wetlands in the continental United States have been destroyed for such diverse uses as agriculture, mining, forestry, and urbanization. Wetlands provide many worthwhile functions, including flood attenuation, wildlife and waterfowl habitat, productivity to support food chains, aquifer recharge, and water quality enhancement. In addition, the maintenance of wetlands in the landscape mosaic is important for the regional hydrologic balance. Wetlands naturally provide water conservation by regulating the rate of evapotranspiration and, in some cases, by providing aquifer recharge. The deliberate application of reclaimed water to wetlands can provide a beneficial use, and therefore reuse, by fulfilling any of the following objectives:

1. To create, restore, and/or enhance wetlands systems
2. To provide additional treatment of reclaimed water prior to discharge to a receiving water body
3. To provide a wet weather disposal alternative for a water reuse system (See Section 3.6.4.)

For wetlands that have been altered hydrologically, application of reclaimed water serves to restore and enhance the wetlands. New wetlands can be created through application of reclaimed water, resulting in a net gain in wetland acreage and functions. In addition, man-made and restored wetlands can be designed and managed to maximize habitat diversity within the landscape.

The application of reclaimed water to wetlands provides compatible uses. Wetlands are often able to enhance the water quality of the reclaimed water without creating undesirable impacts to the wetlands system. This, in turn, enhances downstream natural water systems and provides aquifer recharge.

A great deal of research has been performed documenting the ability of wetlands, both natural and constructed, to provide consistent and reliable water quality improvement. With proper execution of design and construction elements, constructed wetlands exhibit characteristics that are similar to natural wetlands, in that they support similar vegetation and microbes to assimilate pollutants. In addition, constructed wetlands provide wildlife habitat and environmental benefits that are similar to natural wetlands. Constructed wetlands are effective in the treatment of BOD, TSS, nitrogen, phosphorus, pathogens, metals, sulfates, organics, and other toxic substances.

Water quality enhancement is provided by transformation and/or storage of specific constituents within the wetland. The maximum contact of reclaimed water within the wetland will ensure maximum treatment assimilation and storage. This is due to the nature of these processes. If optimum conditions are maintained, nitrogen and BOD assimilation in wetlands will occur indefinitely, as they are primarily controlled by microbial processes and generate gaseous end products. In contrast, phosphorus assimilation in wetlands is finite and is related to the adsorption capacity of the soil and long-term storage within the system. The wetland can provide additional water quality enhancement (polishing) to the reclaimed water product.

In most reclaimed water wetland projects, the primary intent is to provide additional treatment of effluent prior to discharge from the wetland. However, this focus does not negate the need for design considerations that will maximize wildlife habitats, and thereby provide important ancillary benefits. For constructed wetlands, appropriate plant species should be selected based on the type of wetland to be constructed as well as the habitat goals. Treatment performance information is available regarding certain wetland species as well as recommendations regarding species selection (Cronk and Fennessy, 2001).

Wetlands do not provide treatment of total suspended solids. In addition, a salinity evaluation may be necessary because effluent with a high salt content may cause impacts to wetland vegetation. In some cases, salt tolerant vegetation may be appropriate. Design considerations will need to balance the hydraulic and constituent loadings with impacts to the wetland. Impacts to groundwater quality should also be evaluated.

The benefits of a wetland treatment system include:

- Improve water quality through the use of natural systems
- Protect downstream receiving waters
- Provide wetland creation, restoration, or enhancement
- Provide wildlife and waterfowl habitat
- Offer relatively low operating and maintenance costs
- A reasonable development cost
- Maintain “green space”
- Attenuate peak flows
- One component of a “treatment train”; can be used in areas with high water table and/or low permeable soils
- Aesthetic and educational opportunities

Potential limitations of a wetland treatment systems include:

- Significant land area requirements
- May have limited application in urban settings
- Potential for short-circuiting, which will lead to poor performance
- Potential for nuisance vegetation and algae
- May need to be lined to maintain wetland hydroperiod

A number of cities have developed wetlands enhancement systems to provide wildlife habitats as well as treatment. In Arcata, California, one of the main goals of a city wetland project was to enhance the beneficial use of downstream surface waters. A wetlands application system was selected because the wetlands: (1) serve as nutrient sinks and buffer zones, (2) have aesthetic and environmental benefits, and (3) can provide cost-effective treatment through natural systems. The Arcata wetlands system was also designed to function as a wildlife habitat. The Arcata wetlands system, consisting of three 10-acre (4-hectare) marshes, has attracted more than 200 species of birds, provided a fish hatchery for salmon, and contributed directly to the development of the Arcata Marsh and Wildlife Sanctuary (Gearheart, 1988).

Due to a 20-mgd (877-L/s) expansion of the City of Orlando, Florida, Iron Bridge Regional Water Pollution Control Facility in 1981, a wetland system was created to handle the additional flow. Since 1981, reclaimed water from the Iron Bridge plant has been pumped 16 miles (20 kilometers) to a wetland that was created by berming approximately 1,200 acres (480 hectares) of improved pasture. The system is further divided into smaller cells for flow and depth management. The wetland consists of 3 major vegetative areas. The first area, approximately 410 acres (166 hectares), is a deep marsh consisting primarily of cattails and bulrush with nutrient removal as the primary function. The second area consists of 380 acres (154 hectares) of a mixed marsh composed of over 60 submergent and emergent herbaceous species used for nutrient removal and wildlife habitat. The final area, 400 acres (162 hectares) of hardwood swamp, consists of a variety of tree species providing nutrient removal and wildlife habitat. The reclaimed water then flows through approximately 600 acres (240 hectares) of natural wetland prior to discharge to the St. Johns River (Jackson, 1989).

EPA (1999a) indicated that little effort had been made to collect or organize information concerning the habitat functions of treatment wetlands. Therefore, the Treatment Wetland Habitat and Wildlife Use Assessment document (U.S. EPA, 1999a) was prepared. The document was the first comprehensive effort to assemble wide-ranging information concerning the habitat and wildlife use data from surface flow treatment wetlands. The data have been gathered into an electronic format built upon the previous existing North American Treatment Wetland Database funded by the EPA. The report indicates that both natural and constructed treatment wetlands have substantial plant communities and wildlife populations. There are potentially harmful substances in the water, sediments, and biological tissues of treatment wetlands. However, contaminant concentration levels are generally below published action levels. There is apparently no documentation indicating that harm has occurred in any wetland intentionally designed to improve water quality.

The Yelm, Washington, project in Cochrane Memorial Park, is an aesthetically pleasing 8-acre (3-hectare) city park featuring constructed surface and submerged wetlands designed to polish the reclaimed water prior to recharging groundwater. In the center of the park, a fish pond uses the water to raise and maintain rainbow trout for catch and release (City of Yelm, 2003).

A number of states including Florida, South Dakota, and Washington, provide regulations to specifically address the use of reclaimed water in wetlands systems. Where specific regulations are absent, wetlands have been constructed on a case-by-case basis. In addition to state requirements, natural wetlands, which are considered waters of the U.S., are protected under EPA's NPDES Permit and Water Quality Standards programs. The quality of reclaimed water entering natural wetlands is regulated by federal, state and local agencies and must be treated to at least secondary treatment levels or greater to meet water quality standards. Constructed wetlands, on the other hand, which are built and operated for the purpose of treatment only, are not considered waters of the U.S.

Wetland treatment technology, using free water surface wetlands, has been under development, with varying success, for nearly 30 years in the U.S. (U.S. EPA, 1999b). Several key documents that summarize the available information and should be used to assist in the design of wetland treatment systems are: Treatment Wetlands (Kadlec and Kngith, 1996), Free Water Surface Wetlands for Wastewater Treatment (U.S. EPA, 1999b), Constructed Wetlands for Pollution Control: Process, Performance, Design and Operation (IWA, 2000), and the Water Environment Federation Manual of Practice FD-16 Second Edition. Natural Systems for Wastewater Treatment, Chapter 9; Wetland Systems, (WEF, 2001).

2.4.2 Recreational and Aesthetic Impoundments

For the purposes of this discussion, an impoundment is defined as a man-made water body. The use of reclaimed water to augment natural water bodies is discussed in Section 3.4.3. Impoundments may serve a variety of functions from aesthetic, non-contact uses, to boating and fishing, as well as swimming. As with other uses of reclaimed water, the required level of treatment will vary with the intended use of the water. As the potential for human contact increases, the required treatment levels increase. The appearance of the reclaimed water must also be considered when used for impoundments, and treatment for nutrient removal may be required as a means of controlling algae. Without nutrient control, there is a high potential for algae blooms, resulting in odors, an unsightly appearance, and eutrophic conditions.

Reclaimed water impoundments can be easily incorporated into urban developments. For example, landscaping plans for golf courses and residential developments commonly integrate water traps or ponds. These same water bodies may also serve as storage facilities for irrigation water within the site.

In Lubbock, Texas, approximately 4 mgd (175 l/s) of reclaimed water is used for recreational lakes in the Yellowhouse Canyon Lakes Park (Water Pollution Control Federation, 1989). The canyon, which was formerly used as a dump, was restored through the use of reclaimed water to provide water-oriented recreational activities. Four lakes, which include man-made waterfalls, are used for fishing, boating, and water skiing; however, swimming is restricted.

Lakeside Lake is a 14-acre (6-hectare) urban impoundment in Tucson, Arizona. The lake was constructed in the 1970s in the Atterbury Wash to provide fishing, boating, and other recreational opportunities. The lake is lined with soil/cement layers and has a concrete shelf extending 6 feet (2 meters) from the shore around the perimeter. A berm crosses the lake from east to west, creating a north and south bay. The Arizona Game and Fish Department (AGFD) stock the lake with channel catfish, rainbow trout, bluegill, redear and hybrid sunfish, crappie, and large mouth bass on a seasonal basis. The lake was initially supplied by groundwater and surface runoff but began receiving reclaimed water from the Roger Road Treatment Plant in 1990 (up to 45,000 gpd) (170 m^3/d). A mechanical diffuser was installed on the lake bottom in 1992 to improve dissolved oxygen concentrations (PBS&J, 1992).

2.4.3 Stream Augmentation

Stream augmentation is differentiated from a surface water discharge in that augmentation seeks to accomplish a beneficial end, whereas discharge is primarily for disposal. Stream augmentation may be desirable to maintain stream flows and to enhance the aquatic and wildlife habitat as well as to maintain the aesthetic value of the water courses. This may be necessary in locations where a significant volume of water is drawn for potable or other uses, largely reducing the downstream volume of water in the river.

As with impoundments, water quality requirements for stream augmentation will be based on the designated use of the stream as well as the aim to maintain an acceptable appearance. In addition, there may be an emphasis on creating a product that can sustain aquatic life.

The San Antonio Water System in Texas releases its high quality (Type 1) reclaimed water to the San Antonio River. Reclaimed water is used instead of pumped groundwater to sustain the river flow through a city park, zoo, and downtown river walk. A second stream augmentation flows to Salado Creek, where reclaimed water replaces the flow from an abandoned artesian well. Also, reclaimed water is used in a decorative fountain at the City Convention Center with the fountain discharging into a dead-end channel of the downtown river walk waterway.

Several agencies in southern California are evaluating the process in which reclaimed water would be delivered to streams in order to maintain a constant flow of high-quality water for the enhancement of aquatic and wildlife habitat as well as to maintain the aesthetic value of the streams.

2.5 Groundwater Recharge

This section addresses planned groundwater recharge using reclaimed water with the specific intent to replenish groundwater. Although practices such as irrigation may contribute to groundwater augmentation, the replenishment is an incidental byproduct of the primary activity and is not discussed in this section.

The purposes of groundwater recharge using reclaimed water may be: (1) to establish saltwater intrusion barriers in coastal aquifers, (2) to provide further treatment for future reuse, (3) to augment potable or nonpotable aquifers, (4) to provide storage of reclaimed water for subsequent retrieval and reuse, or (5) to control or prevent ground subsidence.

Pumping of aquifers in coastal areas may result in saltwater intrusion, making them unsuitable as sources for potable supply or for other uses where high salt levels are intolerable. A battery of injection wells can be used to create a hydraulic barrier to maintain intrusion control. Reclaimed water can be injected directly into an aquifer to maintain a seaward gradient and thus prevent inland subsurface saltwater intrusion. This may allow for the additional development of inland withdrawals or simply the protection of existing withdrawals.

Infiltration and percolation of reclaimed water takes advantage of the natural removal mechanisms within soils, including biodegradation and filtration, thus providing additional *in situ* treatment of reclaimed water and additional treatment reliability to the overall wastewater management system. The treatment achieved in the subsurface environment may eliminate the need for costly advanced wastewater treatment processes. The ability to implement such treatment systems will depend on the method of recharge, hydrogeological conditions, requirements of the downgradient users, as well as other factors.

Aquifers provide a natural mechanism for storage and subsurface transmission of reclaimed water. Irrigation demands for reclaimed water are often seasonal, requiring either large storage facilities or alternative means of disposal when demands are low. In addition, suitable sites for surface storage facilities may not be available, economically feasible, or environmentally acceptable. Groundwater recharge eliminates the need for surface storage facilities and the attendant problems associated with uncovered surface reservoirs, such as evaporation losses, algae blooms resulting in deterioration of water quality, and creation of odors. Aquifer storage and recovery (ASR) systems are being used in a number of states to overcome seasonal imbalances in both potable and reclaimed water projects. The tremendous volumes of storage potentially available in ASR systems means that a greater percentage of the resource, be it raw water or reclaimed water, can be captured for beneficial use.

While there are obvious advantages associated with groundwater recharge, possible limitations include (Oaksford, 1985):

- Extensive land areas may be needed for spreading basins.

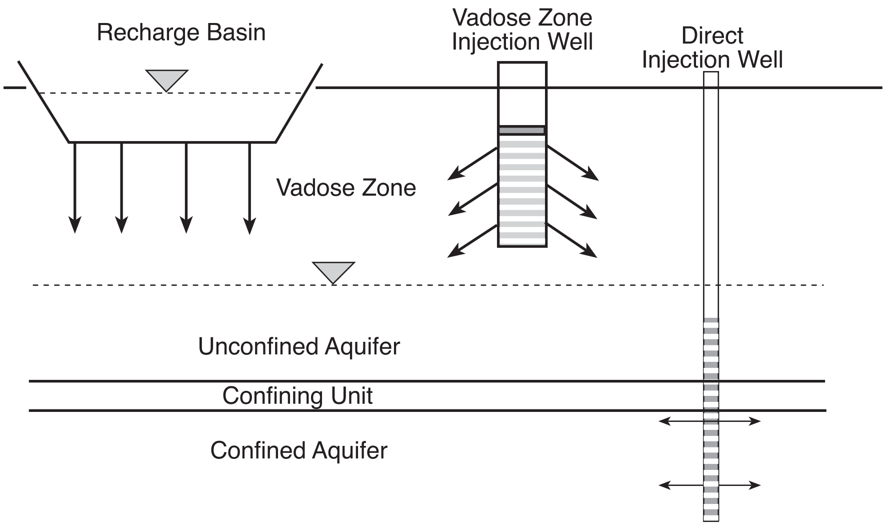
- Costs for treatment, water quality monitoring, and injection/infiltration facilities operations may be prohibitive.

- Recharge may increase the danger of aquifer contamination due to inadequate or inconsistent pretreatment.

- Not all recharged water may be recoverable due to movement beyond the extraction well capture zone or mixing with poor-quality groundwater.

- The area required for operation and maintenance of a groundwater supply system (including the groundwater reservoir itself) is generally larger than that required for a surface water supply system. The fact that the aquifer does not compete with overlying land uses provides a significant advantage. However, this reservoir cannot adversely impact existing uses of the aquifer.

Figure 2-6. Three Engineered Methods for Groundwater Recharge



- Hydrogeologic uncertainties, such as transmissivity, faulting, and aquifer geometry, may reduce the effectiveness of the recharge project in meeting water supply demand.

- Inadequate institutional arrangements or groundwater laws may not protect water rights and may present liability and other legal problems.

The degree to which these factors might limit implementation of a groundwater recharge system is a function of the severity of the site specific impediments balanced against the need to protect existing water sources or expand raw water supplies.

2.5.1 Methods of Groundwater Recharge

Groundwater recharge can be accomplished by surface spreading, vadose zone injection wells, or direct injection. These methods of groundwater recharge use more advanced engineered systems as illustrated in **Figure 2-6** (Fox, 1999). With the exception of direct injection, all engineered methods require the existence of an unsaturated aquifer.

Table 2-8 provides a comparison of major engineering factors that should be considered when installing a groundwater recharge system, including the availability and cost of land for recharge basins (Fox, 1999). If such costs are excessive, the ability to implement injection wells adjacent to the reclaimed water source tends to decrease the cost of conveyance systems for injection wells. Surface spreading basins require the lowest degree of pretreatment while direct injection systems require water quality comparable to drinking water, if potable aquifers are affected. Low-technology treatment options for surface spreading basins include primary and secondary wastewater treatment with the possible use of lagoons and natural systems. Reverse osmosis is commonly used for direct injection systems to prevent clogging, however, some ASR systems have been operating successfully without membrane treatment when water was stored for irrigation. The cost of direct injection systems can be greatly reduced from the numbers presented in Table 2-8 if the aquifer is shallow and nonpotable. Vadose zone injection wells are a relatively new technology, and there is uncertainty over maintenance methods and requirements; however, it is clear that the removal of solids and disinfection is necessary to prevent clogging.

2.5.1.1 Surface Spreading

Surface spreading is a direct method of recharge whereby the water moves from the land surface to the aquifer by infiltration and percolation through the soil matrix.

An ideal soil for recharge by surface spreading would have the following characteristics:

- Rapid infiltration rates and transmission of water

- No layers that restrict the movement of water to the desired unconfined aquifer

- No expanding-contracting clays that create cracks when dried that would allow the reclaimed water to

Table 2-8. Comparison of Major Engineering Factors for Engineered Groundwater Recharge

	Recharge Basins	Vadose Zone Injection Wells	Direct Injection Wells
Aquifer Type	Unconfined	Unconfined	Unconfined or Confined
Pretreatment Requirements	Low Technology	Removal of Solids	High Technology
Estimated Major Capital Costs (US$)	Land and Distribution System	$25,000-75,000 per well	$500,000-1,500,000 per well
Capacity	100-20,000 m^3/hectare-day	1,000-3,000 m^3/d per well	2,000-6,000 m^3/d per well
Maintenance Requirements	Drying and Scraping	Drying and Disinfection	Disinfection and Flow Reversal
Estimated Life Cycle	>100 Years	5-20 Years	25-50 Years
Soil AquiferTreatment	Vadose Zone and Saturated Zone	Vadose Zone and Saturated Zone	Saturated Zone

bypass the soil during the initial stages of the flooding period

- Sufficient clay and/or organic-rich sediment contents to provide large capacities to adsorb trace elements and heavy metals, as well as provide surfaces on which microorganisms can decompose organic constituents. The cation exchange capacity of clays also provides the capacity to remove ammonium ions and allow for subsequent nitrogen transformations

- A supply of available carbon that would favor rapid denitrification during flooding periods, support an active microbial population to compete with pathogens, and favor rapid decomposition of introduced organics (Fox, 2002; Medema and Stuyfsand, 2002; Skjemstad *et al*., 2002). BOD and TOC in the reclaimed water will also be a carbon source

Unfortunately, some of these characteristics are mutually exclusive, and the importance of each soil characteristic is dependent on the purpose of the recharge. For example, adsorption properties may be unimportant if recharge is primarily for storage.

After the applied recharge water has passed through the soil zone, the geologic and subsurface hydrologic conditions control the sustained infiltration rates. The following geologic and hydrologic characteristics should be investigated to determine the total usable storage capacity and the rate of movement of water from the spreading grounds to the area of groundwater withdrawal:

- Physical character and permeability of subsurface deposits

- Depth to groundwater

- Specific yield, thickness of deposits, and position and allowable fluctuation of the water table

- Transmissivity, hydraulic gradients, and pattern of pumping

- Structural and lithologic barriers to both vertical and lateral movement of groundwater

- Oxidation state of groundwater throughout the receiving aquifer

Although reclaimed water typically receives secondary treatment including disinfection and filtration prior to surface spreading, other treatment processes are sometimes provided**.** Depending on the ultimate use of the water and other factors (dilution, thickness of the unsaturated zone, etc.), additional treatment may be required. Nitrogen is often removed prior to surface spreading to eliminate concerns over nitrate contamination of groundwater and to simplify the permitting of storage systems as part of an overall reuse scheme. When extract water is used for potable purposes, post-treatment by disinfection is commonly practiced. In soil-aquifer treatment systems where the extracted water is to be used for nonpotable purposes, satisfactory water quality has been obtained at some sites using primary effluent for spreading providing that the hydraulic loading rates are low to prevent the development of anaerobic conditions (Carlson *et al*., 1982 and Lance *et al.,* 1980).

For surface spreading of reclaimed water to be effective, the wetted surfaces of the soil must remain unclogged, the surface area should maximize infiltration, and the quality of the reclaimed water should not inhibit infiltration.

Operational procedures should maximize the amount of water being recharged while optimizing reclaimed water quality by maintaining long contact times with the soil matrix. If nitrogen removal is desired and the major form of applied nitrogen is total kjehldal nitrogen, then maintenance of the vadose zone is necessary to allow for partial nitrification of ammonium ions adsorbed in the vadose zone. The depth to the groundwater table should be deep enough to prevent breakthrough of adsorbed ammonium to the saturated zone to ensure continuous and effective removal of nitrogen (Fox, 2002).

Techniques for surface spreading include surface flooding, ridge and furrow systems, stream channel modifications, and infiltration basins. The system used is dependent on many factors such as soil type and porosity, depth to groundwater, topography, and the quality and quantity of the reclaimed water (Kopehynski *et al.*, 1996).

a. Surface Flooding

Reclaimed water is spread over a large, gently sloped area (1 to 3 percent grade). Ditches and berms may enclose the flooding area. Advantages are low capital and operations and maintenance (O&M) costs. Disadvantages are large area requirements, evaporation losses, and clogging.

b. Ridge and Furrow

Water is placed in narrow, flat-bottomed ditches. Ridge and furrow is especially adaptable to sloping land, but only a small percentage of the land surface is available for infiltration.

c. Stream Channel Modifications

Berms are constructed in stream channels to retard the downstream movement of the surface water and, thus, increase infiltration into the underground. This method is used mainly in ephemeral or shallow rivers and streams where machinery can enter the streambeds when there is little or no flow to construct the berms and prepare the ground surface for recharge. Disadvantages may include a frequent need for replacement due to wash outs and possible legal restrictions related to such construction practices.

d. Riverbank or Dune Filtration

Riverbank and dune filtration generally rely on the use of existing waterways that have natural connections to groundwater systems. Recharge via riverbank or sand dune filtration is practiced in Europe as a means of indirect potable reuse. It is incorporated as an element in water supply systems where the source is untreated surface water, usually a river. The surface water is infiltrated into the groundwater zone through the riverbank, percolation from spreading basins, canals, lakes, or percolation from drain fields of porous pipe. In the latter 2 cases, the river water is diverted by gravity or pumped to the recharge site. The water then travels through an aquifer to extraction wells at some distance from the riverbank. In some cases, the residence time underground is only 20 to 30 days, and there is almost no dilution by natural groundwater (Sontheimer, 1980). In Germany, systems that do not meet a minimum residence time of 50 days are required to have post-treatment of the recovered water and similar guidelines are applied in the Netherlands. In the Netherlands, dune infiltration of treated Rhine River water has been used to restore the equilibrium between fresh and saltwater in the dunes (Piet and Zoeteman, 1980; Olsthoorn and Mosch, 2002), while serving to improve water quality and provide storage for potable water systems. Dune infiltration also provides protection from accidental spills of toxic contaminants into the Rhine River. Some systems have been in place for over 100 years, and there is no evidence that the performance of the system has deteriorated or that contaminants have accumulated. The City of Berlin has greater than 25 percent reclaimed water in its drinking water supply, and no disinfection is practiced after bank filtration.

e. Infiltration Basins

Infiltration basins are the most widely used method of groundwater recharge. Basins afford high loading rates with relatively low maintenance and land requirements. Basins consist of bermed, flat-bottomed areas of varying sizes. Long, narrow basins built on land contours have been effectively used. Basins constructed on highly permeable soils to achieve high hydraulic rates are called rapid infiltration basins. Basin infiltration rates may sometimes be enhanced or maintained by creation of ridges within the basin (Peyton, 2002). The advantage of ridges within the basin is that materials that cause basin clogging accumulate in the bottom of the ridges while the remainder of the ridge maintains high infiltration rates.

Rapid infiltration basins require permeable soil for high hydraulic loading rates, yet the soil must be fine enough to provide sufficient soil surfaces for biochemical and microbiological reactions, which provide additional treatment to the reclaimed water. Some of the best soils are in the sandy loam, loamy sand, and fine sand range.

When the reclaimed water is applied to the spreading basin, the water percolates through the unsaturated zone to the saturated zone of the groundwater table. The hydraulic loading rate is preliminarily estimated by soil studies, but final evaluation is completed through operating *in situ* test pits or ponds. Hydraulic loading rates for rapid infiltration basins vary from 65 to 500 feet per year (20 to 150 meters per year), but are usually less than 300 feet per year (90 meters per year) (Bouwer, 1988).

Though management techniques are site-specific and vary accordingly, some common principles are practiced in most infiltration basins. A wetting and drying cycle with periodic cleaning of the bottom is used to prevent clogging. Drying cycles allow for desiccation of clogging layers and re-aeration of the soil. This practice helps to maintain high infiltration rates, and microbial populations to consume organic matter, and helps reduce levels of microbiological constituents. Re-aeration of the soil also promotes nitrification, which is a prerequisite for nitrogen removal by denitrification. Periodic maintenance by cleaning of the bottom may be done by deep ripping of the soils or by scraping the top layer of soil. Deep ripping sometimes causes fines to migrate to deeper levels where a deep clogging layer may develop. The Orange County Water District (California) has developed a device to continuously remove clogging materials during a flooding cycle.

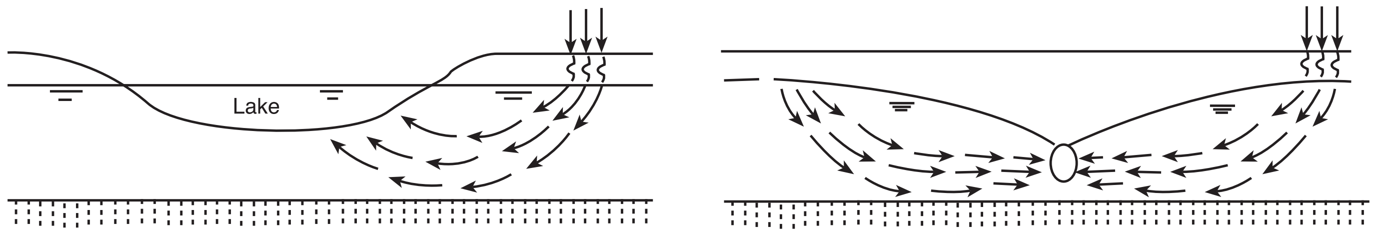
Spreading grounds can be managed to avoid nuisance conditions such as algae growth and insect breeding in the percolation ponds. Generally, a number of basins are rotated through filling, draining, and drying cycles. Cycle length is dependent on both soil conditions and the distance to the groundwater table. This is determined through field-testing on a case-by-case basis. Algae can clog the bottom of basins and reduce infiltration rates. Algae further aggravate soil clogging by removing carbon dioxide, which raises the pH, causing precipitation of calcium carbonate. Reducing the detention time of the reclaimed water within the basins minimizes algal growth, particularly during summer periods where solar intensity and temperature increase algal growth rates. The levels of nutrients necessary to stimulate algal growth are too low for practical consideration of nutrient removal as a method to control algae. Also, scarifying, rototilling, or discing the soil following the drying cycle can help alleviate clogging potential, although scraping or "shaving" the bottom to remove the clogging layer is more effective than discing it. Removing the hard precipitant using an underwater machine has also been accomplished (Mills, 2002).

2.5.1.2 Soil-Aquifer Treatment Systems

Soil-Aquifer Treatment (SAT) systems usually are designed and operated such that all of the infiltrated water is recovered via wells, drains, or seepage into surface water. Typical SAT recharge and recovery systems are shown in **Figure 2-7**. SAT systems with infiltration basins require unconfined aquifers, vadose zones free of restricting layers, and soils that are coarse enough to allow high infiltration rates, but fine enough to provide adequate filtration. Sandy loams and loamy or fine sands are the preferred surface soils in SAT systems. Recent work on SAT removal of dissolved organic carbon (DOC), trace organics, and organic halides has shown positive results (Fox *et al*., 2001; Drewes *et al*., 2001). The majority of trace organic compounds are removed by biodegradation and organic chlorine and organic bromine are removed to ambient levels. Short-term DOC removal is enhanced by maintaining aerobic conditions in the unsaturated zone (Fox, 2002).

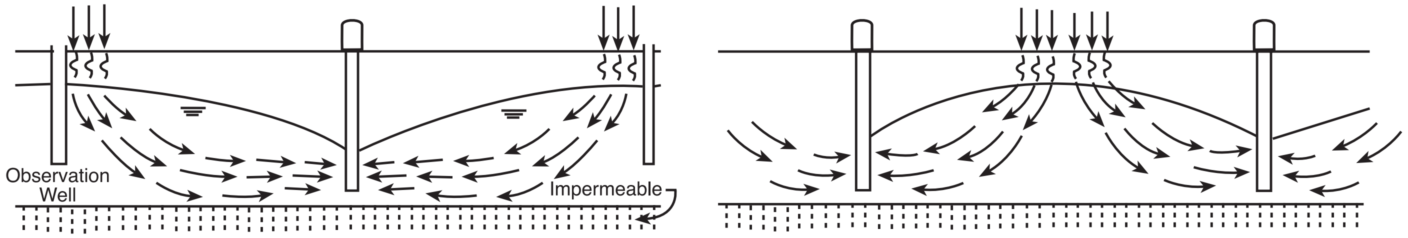
In the U.S., municipal wastewater usually receives conventional primary and secondary treatment prior to SAT. However, since SAT systems are capable of removing more BOD than is in secondary effluent, efficient secondary treatment may not be necessary in cases where the wastewater is subjected to SAT and subsequently reused for nonpotable purposes. Higher organic content may enhance nitrogen removal by denitrification in the SAT system and may enhance removal of synthetic organic compounds by stimulating greater microbiological activity in the soil. However low hydraulic loading

Figure 2-7. Schematic of Soil-Aquifer Treatment Systems



A. Drainage of Reclaimed Water into Stream, Lake, or Low Area

B. Collection of Reclaimed Water by Subsurface Drain



C. Infiltration Area in Two Parallel Rows and Line of Wells Midway Between

D. Infiltration Areas in Center Surrounded by a Circle of Wells

rates must be used to prevent anaerobic conditions from developing which can prevent complete biodegradation in the sub-surface. More frequent cleaning of the basins would increase the cost of the SAT, but would not necessarily increase the total system cost.

Where hydrogeologic conditions permit groundwater recharge with surface infiltration facilities, considerable improvement in water quality may be achieved through the movement of wastewater through the soil, unsaturated zone, and saturated zone. **Table 2-9** provides an example of overall improvement in the quality of secondary effluent in a groundwater recharge SAT system. These water quality improvements are not limited to soil aquifer treatment systems and are applicable to most groundwater recharge systems where aerobic and/or anoxic conditions exist and there is sufficient storage time.

These data are the result of a demonstration project in the Salt River bed, west of Phoenix, Arizona (Bouwer and Rice, 1989). The cost of SAT has been shown to be less than 40 percent of the cost of equivalent aboveground treatment (Bouwer, 1991). It should also be noted that the SAT product water was recovered from a monitoring well located adjacent to the recharge basin. Most SAT systems allow for considerable travel time in the aquifer and provide the opportunity for improvement in water quality.

An intensive study, entitled, “An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse,” was conducted to assess the sustainability of several different SAT systems with different site characteristics and effluent pretreatments (AWWARF, 2001). (See case study 2.7.16). In all of the systems studied, water quality improvements were similar to the results presented by Bouwer (1984). When significant travel times in the vadose or saturated zone existed, water quality improvements exceeded the improvements actually observed by Bouwer (1984).

The 3 main engineering factors that can affect the performance of soil aquifer treatment systems are: effluent pretreatment, site characteristics, and operating conditions (Fox, 2002).

Effluent Pretreatment – Effluent pretreatment directly impacts the concentrations of biodegradable matter that are applied to a percolation basin. Therefore, it is a key factor that can be controlled as part of a SAT system. One of the greatest impacts of effluent pretreatment during SAT is near the soil/water interface where high biological activity is observed. This condition occurs because both the highest concentrations of biodegradable matter and oxygen are present. Both organic carbon and ammonia may be biologically oxidized. They are the water quality parameters that control the amount of oxygen demand in applied effluents. One of the greatest impacts of effluent pretreatment is to the total oxygen demand of applied water. Near the soil/water surface, biological activity with an effluent that has high total oxygen demand will result in the use of all the dissolved oxygen. Aerobic

Table 2-9. Water Quality at Phoenix, Arizona, SAT System

	Secondary Effluent (mg/l)	Recovery Well Samples (mg/l)
Total dissolved solids	750	790
Suspended solids	11	1
Ammonium nitrogen	16	0.1
Nitrate nitrogen	0.5	5.3
Organic nitrogen	1.5	0.1
Phosphate phosphorus	5.5	0.4
Fluoride	1.2	0.7
Boron	0.6	0.6
Biochemical oxygen demand	12	<1
Total organic carbon	12	1.9
Zinc	0.19	0.03
Copper	0.12	0.016
Cadmium	0.008	0.007
Lead	0.082	0.066
Fecal coliforms/100 mL[a]	3500	0.3
Viruses, pfu/100 mL[b]	2118	<1

[a] Chlorinated effluent

[b] Undisinfected effluent

Source: Adapted from Bouwer and Rice, 1989.

conditions can be maintained with effluents that have low total oxygen demand. It should also be noted that the majority of oxygen demand exerted during wetting is from the oxidation of organic carbon while ammonia is removed by adsorption (Kopchynski *et al*., 1996).

Site Characteristics – Site characteristics are a function of local geology and hydrogeology. Site selection is often dependent on a number of practical factors including suitability for percolation, proximity to conveyance channels and/or water reclamation facilities, and the availability of land. The design of SAT systems must accommodate the site characteristics. The design options are primarily limited to the size and depth of percolation basins and the location of recovery wells. Increasing the depth of percolation basins can be done to access high permeability soils. The location of recovery wells affects the travel time for subsurface flow and mounding below the percolation basins.

Operating Conditions – The operation of SAT systems with wet/dry cycles is a common operating strategy. The primary purpose of wet/dry cycle operation is to control the development of clogging layers and maintain high infiltration rates, and in some cases, to disrupt insect life cycles. As a clogging layer develops during a wetting cycle, infiltration rates can decrease to unacceptable rates. The drying cycle allows for the desiccation of the clogging layer and the recovery of infiltration rates during the next wetting cycle. Operating conditions are dependent on a number of environmental factors including temperature, precipitation and solar incidence. Therefore, operating conditions must be adjusted to both local site characteristics and weather patterns.

2.5.1.3 Vadose Zone Injection

Vadose zone injection wells for groundwater recharge with reclaimed water were developed in the 1990s and have been used in several different cities in the Phoenix, Arizona, metropolitan area. Typical vadose zone injection wells are 6 feet (2 meters) in diameter and 100 to 150 feet (30 to 46 meters) deep. They are backfilled with porous media and a riser pipe is used to allow for water to enter at the bottom of the injection well to prevent air entrainment. An advantage of vadose zone injection wells is the significant cost savings as compared to direct injection wells. The infiltration rates per well are often similar to direct injection wells. A significant disadvantage is that they cannot be backwashed and a severely clogged well can be permanently destroyed. Therefore, reliable pretreatment is considered essential to maintaining the performance of a vadose zone injection well. Because of the considerable cost savings associated with vadose zone injection wells as compared to direct injection wells, a life cycle of 5 years for a vadose injection well can still make the vadose zone injection well the economical choice. Since vadose zone injection wells allow for percolation of water through the vadose zone and flow in the saturated zone, one would expect water quality improvements commonly associated with soil aquifer treatment to be possible.

2.5.1.4 Direct Injection

Direct injection involves pumping reclaimed water directly into the groundwater zone, which is usually a well-confined aquifer. Direct injection is used where groundwater is deep or where hydrogeological conditions are not conducive to surface spreading. Such conditions might include unsuitable soils of low permeability, unfavorable topography for construction of basins, the desire to recharge confined aquifers, or scarcity of land. Direct injection into a saline aquifer can create a freshwater “plume” from which water can be extracted for reuse, particularly in ASR systems (Pyne, 1995). Direct injection is also an effective method for creating barriers against saltwater intrusion in coastal areas.

Direct injection requires water of higher quality than for surface spreading because of the absence of vadose zone and/or shallow soil matrix treatment afforded by surface spreading and the need to maintain the hydraulic capacity of the injection wells, which are prone to physical, biological, and chemical clogging. Treatment processes beyond secondary treatment that are used prior to injection include disinfection, filtration, air stripping, ion exchange, granular activated carbon, and reverse osmosis or other membrane separation processes. By using these processes or various subsets in appropriate combinations, it is possible to satisfy present water quality requirements for reuse. In many cases, the wells used for injection and recovery are classified by the EPA as Class V injection wells. Some states require that the injected water must meet drinking water standards prior to injection into a Class V well.

For both surface spreading and direct injection, locating the extraction wells as great a distance as possible from the recharge site increases the flow path length and residence time in the underground, as well as the mixing of the recharged water with the natural groundwater. Treatment of organic parameters does occur in the groundwater system with time, especially in aerobic or anoxic conditions (Gordon *et al*., 2002; Toze and Hanna, 2002).

There have been several cases where direct injection systems with wells providing significant travel time have allowed for the passage of emerging pollutants of concern, such as NDMA and 1,4-dioxane into recovery wells. In these cases, the final pretreatment step was reverse osmosis. Since reverse osmosis effectively removes almost all nutrients, improvements in water quality by microbial activity might be limited in aquifers that receive reverse osmosis treated water. These emerging pollutants of concern have not been observed in soil aquifer treatment systems using spreading basins where microbial activity in the subsurface is stimulated.

Ideally, an injection well will recharge water at the same rate as it can yield water by pumping. However, conditions are rarely ideal. Injection/withdrawal rates tend to decrease over time. Although clogging can easily be remedied in a surface spreading system by scraping, discing, drying and other methods, remediation in a direct injection system can be costly and time consuming. The most frequent causes of clogging are accumulation of organic and inorganic solids, biological and chemical contaminants, and dissolved air and gases from turbulence. Very low concentrations of suspended solids, on the order of 1 mg/l, can clog an injection well. Even low concentrations of organic contaminants can cause clogging due to bacteriological growth near the point of injection.

Many criteria specific to the quality of the reclaimed water, groundwater, and aquifer material have to be taken into consideration prior to construction and operation. These include possible chemical reactions between the reclaimed water and groundwater, iron precipitation, ionic reactions, biochemical changes, temperature differences, and viscosity changes. Most clogging problems are avoided by proper pretreatment, well construction, and proper operation (Stuyzand, 2002). Injection well design and operations should consider the need to occasionally reverse the flow or backflush the well much like a conventional filter or membrane. In California and Arizona, injection wells are being constructed or retrofitted with dedicated pumping or backflushing equipment to maintain injection capacity and reduce the frequency of major well redevelopment events.

2.5.2 Fate of Contaminants in Recharge Systems

The fate of contaminants is an important consideration for groundwater recharge systems using reclaimed water. Contaminants in the subsurface environment are subject to processes such as biodegradation by microorganisms, adsorption and subsequent biodegradation, filtration, ion exchange, volatilization, dilution, chemical oxidation and reduction, chemical precipitation and complex formation, and photochemical reactions (in spreading basins) (Fox, 2002; Medema and Stuyzand, 2002). For surface spreading operations, chemical and microbiological constituents are removed in the top 6 feet (2 meters) of the vadose zone at the spreading site.

2.5.2.1 Particulate Matter

Particles larger than the soil pores are strained off at the soil-water interface. Particulate matter, including some bacteria, is removed by sedimentation in the pore spaces of the media during filtration. Viruses are mainly removed by adsorption and interaction with anaerobic bacteria (Gordon *et al*., 2002). The accumulated particles gradually form a layer restricting further infiltration. Suspended solids that are not retained at the soil/water interface may be effectively removed by infiltration and adsorption in the soil profile. As water flows through passages formed by the soil particles, suspended and colloidal solids far too small to be retained by straining are thrown off the streamline through hydrodynamic actions, diffusion, impingement, and sedimentation. The particles are then intercepted and adsorbed onto the surface of the stationary soil matrix. The degree of trapping and adsorption of suspended particles by soils is a function of the suspended solids concentration, soil characteristics, and hydraulic loading. Suspended solids removal is enhanced by longer travel distances underground.

For dissolved inorganic constituents to be removed or retained in the soil, physical, chemical, or microbiological reactions are required to precipitate and/or immobilize the dissolved constituents. Chemical reactions that are important to a soil's capability to react with dissolved inorganics include cation exchange reactions, precipitation, surface adsorption, chelation, complexation, and weathering (dissolution) of clay minerals.

While inorganic constituents such as chloride, sodium, and sulfate are unaffected by ground passage, many other inorganic constituents exhibit substantial removal. For example, iron and phosphorus removal in excess of 90 percent has been achieved by precipitation and adsorption in the underground, although the ability of the soil to remove these and other constituents may decrease over time. Heavy metal removal varies widely for different elements, ranging from 0 to more than 90 percent, depending on the speciation of the influent metals.

2.5.2.2 Dissolved Organic Constituents

Dissolved organic constituents are subject to biodegradation and adsorption during recharge. Biodegradation mainly occurs by microorganisms attached to the media surface (Skjemstad *et al*., 2002). The rate and extent of biodegradation is strongly influenced by the nature of the organic substances and by the presence of electron acceptors such as dissolved oxygen and nitrate. There are indications that biodegradation is enhanced if the aquifer material is finely divided and has a high specific surface area, such as fine sand or silt. However, such conditions can lead to clogging by bacterial growths. Coarser aquifer materials such as gravel and some sands have greater permeability and, thus, less clogging. However, biodegradation may be less rapid and perhaps less extensive. The biodegradation of easily degradable organics occurs a short distance (few meters) from the point of recharge. A large body of literature shows that biodegradable compounds do not survive long in anoxic or aerobic groundwater and only chemical compounds that have high solubility and extensive half-lives are of great concern (i.e. chlorinated solvents). Specific groups of compounds also require longer times due to their complex biodegradation pathways; however, the product water from SAT may be compared to membrane processed water since select groups of compounds may persist in both cases (Drewes *et al.*, 2003).

The end products of complete degradation under aerobic conditions include carbon dioxide, sulfate, nitrate, phosphate, and water. The end products under anaerobic conditions include carbon dioxide, nitrogen, sulfide, and methane. The mechanisms operating on refractory organic constituents over long time periods typical of groundwater environments are not well understood. However, sustainable removal has been observed over significant time periods demonstrating that biodegradation is the major removal mechanism since accumulation of organic carbon in the sub-surface is not observed (AWWARF, 2001). The degradation of organic contaminants may be partial and result in a residual organic product that cannot be further degraded at an appreciable rate (Khan and Rorije, 2002), and such metabolites are often difficult to identify and detect (Drewes *et al.,* 2001).

Results were presented in a 2001 AWWARF study entitled, "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse." This investigation demonstrated the potential removal ability of an entire SAT system where travel times are expected to be on the order of 6 months or greater before water is recovered. Since most trace organic compounds are present at concentrations that cannot directly support microbial growth, the sustainable removal mechanism for these compounds is co-metabolic. The microbes catalyze the mineralization of the organic compounds, but the microorganisms do not get enough energy from the trace organic compounds to support growth. In the study, the majority of compounds analyzed were below detection limits after 6 months of travel time in the sub-surface. Therefore, it appears that significant time in the sub-surface is required in a microbially active aquifer to efficiently remove trace organics that are potentially biodegradable by cometabolism. One would expect similar results for aerobic or anoxic (nitrate-reducing) aquifers. But results are not conclusive for anaerobic aquifers. Several pharmaceutical compounds do appear to be recalcitrant in a microbially active aquifer at concentrations in the part per trillion range. A bench scale study of an unconfined aquifer irrigated with reclaimed water found antipyrine moved rapidly through the soil, while caffeine was subject to adsorption and microbial degradation (Babcock *et al.,* 2002).

Endocrine-disrupting activity has also been evaluated during soil aquifer treatment and results consistently suggest that soil aquifer treatment rapidly reduces endocrine-disrupting activity to ambient levels (Turney *et al.,* In Press). Since the majority of compounds that are suspected to cause endocrine disruption are either strongly adsorbed or biodegradable, the results are consistent with microbial activity providing sustainable removal of organics during soil aquifer treatment.

2.5.2.3 Nitrogen

The 2 major forms of nitrogen in reclaimed water are typically ammonia and nitrate. As reported by AWWARF (2001), the concentrations and forms of nitrogen in applied effluents are a strong function of effluent pretreatment. Secondary effluents contained ammonia nitrogen at concentrations up to 20 mg-N/l while denitrified effluents contained primarily nitrate nitrogen at concentrations less than 10 mg-N/l. Ammonia nitrogen is the major form of oxygen demand in secondary effluents that are not nitrified.

Nitrogen can be efficiently removed during effluent pretreatment; however, appropriately operated SAT systems have the capacity to remove nitrogen in secondary effluents. The removal of nitrogen appears to be a sustainable, biologically mediated process. When ammonia is present in reclaimed water, the ammonia is removed by adsorption during wetting when insufficient oxygen is available to support nitrification. Nitrification of adsorbed ammonia occurs during subsequent drying cycles as re-aeration of vadose zone soils occurs. Nitrate is weakly adsorbed and is transported with bulk water flow during SAT. Removal of nitrate was consistently observed at all sites where anoxic or anaerobic conditions were present (AWWARF, 2001). The biological removal mechanism for denitrification was found to be site specific.

The 2001 AWWARF study entitled, “An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse.” investigated the mechanism of anaerobic ammonia oxidation (ANAMMOX) as a sustainable mechanism for nitrogen removal. During SAT, it is possible for adsorbed ammonia to serve as an electron donor to convert nitrate to nitrogen gas by ANAMMOX. Evidence for ANAMMOX activity was obtained in soils obtained from the Tucson site. Since adsorbed ammonia is available for nitrification when oxygen reaches soils containing adsorbed ammonia, ANAMMOX activity could occur as nitrate percolates through soils containing adsorbed ammonia under anoxic conditions. This implies that there is a sustainable mechanism for nitrogen removal during SAT when effluent pretreatment does not include nitrogen removal and the majority of applied nitrogen is ammonia. Appropriate wetting/drying cycles are necessary to promote nitrification in the upper vadose zone during drying cycles. The more mobile nitrate passes over soils with adsorbed ammonia under anoxic conditions deeper in the vadose zone. Extended wetting cycles with short dry cycles will result in ammonia adsorbed at increasing depths as adsorption sites become exhausted. Extended drying cycles will result in reaeration of soils at greater depths resulting in nitrification of adsorbed ammonia at greater depths. A mechanistic model was developed to provide guidelines for the operation of soil aquifer treatment systems to sustain nitrogen removal (Fox, 2003).

2.5.2.4 Microorganisms

The survival or retention of pathogenic microorganisms in the subsurface depends on several factors including climate, soil composition, antagonism by soil microflora, flow rate, and type of microorganism. At low temperatures (below 4 °C or 39 °F) some microorganisms can survive for months or years. The die-off rate is approximately doubled with each 10 °C (18 °F) rise in temperature between 5 and 30 °C (41 and 86 °F) (Gerba and Goyal, 1985). Rainfall may mobilize bacteria and viruses that had been filtered or adsorbed, and thus, enhance their transport.

The nature of the soil affects survival and retention. For example, rapid infiltration sites where viruses have been detected in groundwater were located on coarse sand and gravel types. Infiltration rates at these sites were high and the ability of the soil to adsorb the viruses was low. Generally, coarse soil does not inhibit virus migration. Other soil properties, such as pH, cation concentration, moisture holding capacity, and organic matter do have an affect on the survival of bacteria and viruses in the soil. Resistance of microorganisms to environmental factors depends on the species and strains present.

Drying the soil will kill both bacteria and viruses. Bacteria survive longer in alkaline soils than in acid soils (pH 3 to 5) and when large amounts of organic matter are present. In general, increasing cation concentration and decreasing pH and soluble organics tend to promote virus adsorption. Bacteria and larger organisms associated with wastewater are effectively removed after percolation through a short distance of the soil mantle. Lysimeter studies showed a greater than 99 percent removal of bacteria and 95 to 99 percent removal of viruses (Cuyk *et al.*, 1999). Factors that may influence virus movement in groundwater are given in **Table 2-10**. Proper treatment (including disinfection) prior to recharge, site selection, and management of the surface spreading recharge system can minimize or eliminate the presence of microorganisms in the groundwater. Once the microorganisms reach the groundwater system, the oxidation state of the water significantly affects the rate of removal (Medema and Stuyfzand, 2002; Gordon *et al*., 2002).

2.5.3 Health and Regulatory Considerations

Constraints on groundwater recharge are conditioned by the use of the extracted water and include health concerns, economic feasibility, physical limitations, legal restrictions, water quality constraints, and reclaimed water availability. Of these constraints, health concerns are the most important as they pervade almost all recharge projects (Tsuchihashi *et al*., 2002). Where reclaimed water will be ingested, health effects due to prolonged exposure to low levels of contaminants must be considered as well as the acute health effects from pathogens or toxic substances. [See Section 3.4.1 Health Assessment of Water Reuse and Section 2.6 Augmentation of Potable Supplies.]

One problem with recharge is that boundaries between potable and nonpotable aquifers are rarely well defined. Some risk of contaminating high quality potable groundwater supplies is often incurred by recharging “nonpotable” aquifers. The recognized lack of knowledge about the fate and long-term health effects of contaminants found in reclaimed water obliges a conservative approach in setting water quality standards and monitoring requirements for groundwater recharge. Because of these uncertainties, some states have set stringent water quality requirements and require high levels of treatment – in some cases, organic removal processes – where groundwater recharge impacts potable aquifers.

2.6 Augmentation of Potable Supplies

This section discusses indirect potable reuse via surface water augmentation, groundwater recharge, and direct potable reuse. For the purpose of this document, indirect potable reuse is defined as the augmentation of a community’s raw water supply with treated wastewater followed by an environmental buffer (Crook, 2001). The treated wastewater is mixed with surface and/or groundwater, and the mix typically receives additional treatment before entering the water distribution system. Direct potable reuse is defined as the introduction of treated wastewater directly into a water distribution system without intervening storage (pipe-to-pipe) (Crook, 2001). Both such sources of potable water are, at face value, less desirable than using a higher quality source for drinking.

Table 2-10. Factors that May Influence Virus Movement to Groundwater

Factor	Comments
Soil Type	Fine-textured soils retain viruses more effectively than light-textured soils. Iron oxides increase the adsorptive capacity of soils. Muck soils are generally poor adsorbents.
pH	Generally, adsorption increases when pH decreases. However, the reported trends are not clear-cut due to complicating factors.
Cations	Adsorption increases in the presence of cations. Cations help reduce repulsive forces on both virus and soil particles. Rainwater may desorb viruses from soil due to its low conductivity.
Soluble Organics	Generally compete with viruses for adsorption sites. No significant competition at concentrations found in wastewater effluents. Humic and fulvic acids reduce virus adsorption to soils.
Virus Type	Adsorption to soils varies with virus type and strain. Viruses may have different isoelectric points.
Flow Rate	The higher the flow rate, the lower virus adsorption to soils.
Saturated vs. Unsaturated Flow	Virus movement is less under unsaturated flow conditions.

Source: Gerba and Goyal, 1985.

A guiding principle in the development of potable water supplies for almost 150 years was stated in the 1962 Public Health Service Drinking Water Standards: ". . . water supply should be taken from the most desirable source which is feasible, and efforts should be made to prevent or control pollution of the source." This was affirmed by the EPA (1976) in its Primary Drinking Water Regulations: " . . priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable. . . "

2.6.1 Water Quality Objectives for Potable Reuse

Development of water quality requirements for either direct or indirect potable reuse is difficult. The task involves a risk management process that entails evaluating, enumerating, and defining the risks and potential adverse health impacts that are avoided by the practice of physically separating wastewater disposal and domestic water supply. By physically separating wastewater disposal and domestic water supply by environmental storage, the life cycle of waterborne diseases can be broken, thereby preventing or reducing disease in the human population. As the physical proximity and perceived distance between reclaimed water and domestic water supply decreases, human contact with and consumption of reclaimed water become more certain, and the potential impacts to human health become harder to define.

From a regulatory standpoint, there is a tendency to use the Safe Drinking Water Act (SDWA) National Primary Drinking Water Regulations (NPDWR) as a starting point for defining potable water quality objectives. For years, water reuse advocates have argued that reclaimed water from municipal wastewater meets the requirements of the NPDWR. However, the original purpose of the NPDWR was not intended to define potable water quality when the source is municipal wastewater.

There has been a dramatic increase in the ability to detect chemicals in recent years. Considering the hundreds of thousands of chemicals manufactured or used in the manufacturing of products, the number of chemicals regulated by the SDWA represent a small fraction of these compounds. The 1986 SDWA amendments required EPA to promulgate 25 new maximum contaminant levels (MCLs), or drinking water treatment requirements, for specific contaminants every 3 years (Calabrese *et al.* 1989). However, the 1996 SDWA amendments reduced that number by requiring the agency to "consider" regulating up to 5 contaminants every 5 years. **Figure 2-8** shows the potential impact to the number of regulated compounds under the NPDWR as outlined by the 1986 and 1996 SDWA amendments.

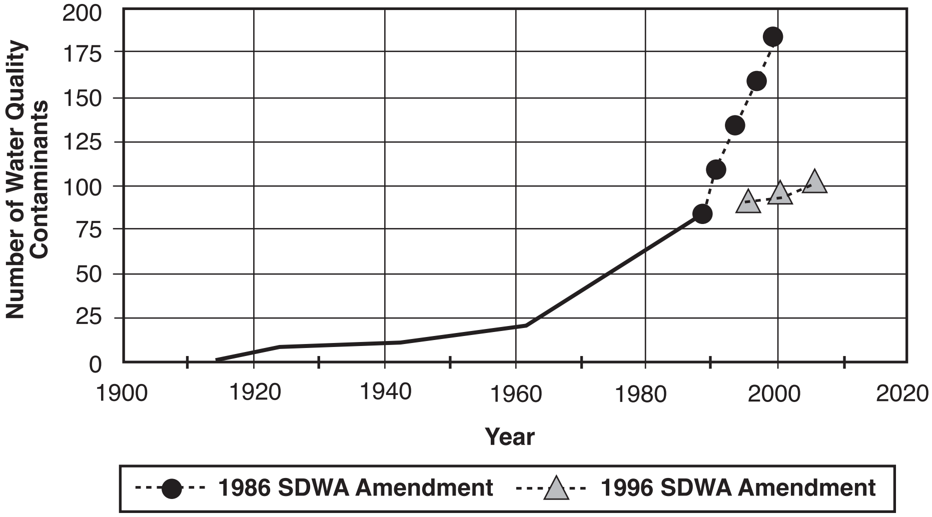
MCLs are thought of as standards for individual chemicals. However, contaminants can be regulated by specifying treatment processes and performance standards without directly measuring the contaminant. Because of the sheer numbers of potential chemicals, traditional wastewater treatment processes are not the panacea for all potable water quality concerns, particularly since current analytical methods are insufficient to identify all potential contaminants at concentrations of health significance. If the analytical method does not have sufficient sensitivity, then the presence of contaminants may go unobserved. Water reuse agencies in California observed problems with specific chemicals and trace organics being discharged to wastewater treatment plants. These elements were detected in the final effluents, only after analytical detection limits were lowered.

Additional concerns have been raised regarding the fate and transport of trace organic compounds (Daughton and Temes 1999 and Sedlak *et al.,* 2000). These include endocrine disruptors, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products (antibacterial soaps, sunscreen, bath gels, etc.) that are present in municipal wastewaters. None of these individual compounds are regulated or monitored by maximum contaminant levels (MCLs) in the SDWA.

Some indirect water reuse projects (San Diego and Denver) have started using toxicological assays to compare the drinking water source to the reclaimed water. While these studies have generally shown that the assay results show no difference between the reclaimed water and the source water used for domestic supply, there are concerns that current toxicological methods are not sensitive enough to characterize the impact of reclaimed water on human health in the 10^{-4} and 10^{-6} risk range. As part of the 1996 SDWA amendments, EPA is charged with developing an evaluation that considers the health impact of an identified contaminant to sensitive subpopulations.

In 1996 and 1999, the Rand Corporation conducted epidemiological studies to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.,* 1996 and Sloss *et al.,* 1999). The 1996 ecologic study design looked at selected infectious disease occurrence as well as cancer incidence and mortality. Investigators could find no link between the incidence of infectious disease or cancer rates and exposure to reclaimed water. The 1999 study focused on adverse birth outcomes (prenatal development, infant mortality, and birth defects). Similar results were reported for the 1999 study; there was no association between reclaimed water and adverse

Figure 2-8. Contaminants Regulated by the National Primary Drinking Water Regulations



birth outcomes. However, epidemiological studies are limited, and these studies are no exception. Researchers noted several weaknesses in their study design that contribute to the overall uncertainty associated with the findings. They found that it was difficult to get an accurate assessment of reclaimed water exposure in the different areas.

In addition to the uncertainties associated with toxicological and epidemiological studies, current analytical systems are insensitive to the contaminants of concern. Surrogates are often used as performance-based standards. Microbiological water quality objectives are defined by surrogates or treatment performance standards that do not measure the contaminant of concern, but nevertheless, provide some indication the treatment train is operating properly, and the product is of adequate quality. It is then assumed that under similar conditions of operation, the microbiological contaminant of concern is being removed concurrently. For example, coliforms are an indicator of microbiological water quality. While there are documents discussing the criteria for an ideal surrogate (AWWARF and KIWA, 1988), no surrogate meets every criterion. Hence, the shortcomings of the surrogate should also be remembered.

In 1998, the National Research Council (NRC) published, “Issues in Potable Reuse,” an update of its 1980 report. In this update, the NRC did not consider addressing direct potable reuse for the reason that, without added protection (such as storage in the environment), the NRC did not view direct potable reuse as a viable option. Rather than face the risks associated with direct, pipe-to-pipe potable reuse, the NRC emphasized that there are far more manageable, nonpotable reclaimed water applications that do not involve human consumption. The focus of health impacts shifts from the acute microbiologically-induced diseases, for nonpotable reuse, to the diseases resulting from long-term chronic exposure, e.g., cancer or reproductive effects, for potable reuse.

While direct potable reuse may not be considered a viable option at this time, many states are moving forward with indirect potable reuse projects. For many cities or regions, the growing demand for water, lack of new water resources, and frequent calls for water conservation in low and consecutive low rainfall years have resulted in the need to augment potable supplies with reclaimed water. Indeed, in some situations, indirect potable reuse may be the next best alternative to make beneficial use of the resource. Further, the lack of infrastructure for direct nonpotable reuse may be too cumbersome to implement in a timely manner.

With a combination of treatment barriers and added protection provided by environmental storage, the problem of defining water quality objectives for indirect potable reuse is manageable. By employing treatment beyond typical disinfected tertiary treatment, indirect potable reuse projects will provide additional organics removal and environmental storage (retention time) for the reclaimed water, thereby furnishing added protection against the unknowns and uncertainty associated with trace organics. However, these processes will be operated using performance standards based on surrogates that do not address specific contaminants. Until better source control and protection programs are in place to deal with the myriad of chemicals discharged into the wastewater collection systems, or until analytical and toxicological testing becomes more sensitive, the concern over low-level contaminant concentrations will remain. If and when contaminants are found, treatment technologies can be applied to reduce the problem. EPA (2001) has identified several drinking water treatment processes capable of removing some endocrine disruptors. Examples are granular activated carbon and membrane treatment.

Potable reuse, whether direct or indirect, is not a risk-free practice. No human engineered endeavor is risk-free, but with appropriate treatment barriers (and process control) water quality objectives will be defined by an acceptable risk. Given the unknowns, limitations, and uncertainty with the current state of science and technology, it is not possible to establish the threshold at which no observed effect would occur, just as it is not reasonable to expect current scientific techniques to demonstrate the absence of an impact on human health.

2.6.2 Surface Water Augmentation for Indirect Potable Reuse

For many years, a number of cities have elected to take water from large rivers that receive substantial wastewater discharges. These cities based their decisions, in part, on the assurance that conventional filtration and disinfection eliminates the pathogens responsible for waterborne infectious disease. These water sources were generally less costly and more easily developed than upland supplies or underground sources. Such large cities as Philadelphia, Cincinnati, and New Orleans, drawing water from the Delaware, Ohio and Mississippi Rivers, respectively, are thus practicing indirect potable water reuse. The many cities upstream of their intakes can be characterized as providing water reclamation in their wastewater treatment facilities, although they were not designed, nor are they operated, as potable water sources. NPDES permits for these discharges are intended to make the rivers “fishable and swimmable,” and generally do not reflect potable water requirements downstream. These indirect potable reuse systems originated at a time when the principal concern for drinking water quality was the prevention of enteric infectious diseases and issues relating to chemical contaminants received lesser attention. Nevertheless, most cities do provide water of acceptable quality that meets current drinking water regulations. Unplanned or incidental indirect potable reuse via surface water augmentation has been, and will continue to be, practiced widely.

More recent indirect potable reuse projects that involve surface water augmentation are exemplified by the Upper Occoquan Sewage Authority (UOSA) treatment facilities in northern Virginia, which discharge reclaimed water into Bull Run, just above Occoquan Reservoir, a water supply source for Fairfax County, Virginia. The UOSA plant, in operation since 1978, provides AWT that is more extensive than required treatment for nonpotable reuse and accordingly provides water of much higher quality for indirect potable reuse than is required for nonpotable reuse (Joint Task Force, 1998). In Clayton County, Georgia, wastewater receives secondary treatment, and then undergoes land treatment, with the return subsurface flow reaching a stream used as a source of potable water. The Clayton County project, which has been in operation for 20 years, is being upgraded to include wetlands treatment and enhancements at the water treatment plant (Thomas *et al*., 2002).

While UOSA now provides a significant portion of the water in the system, varying from an average of about 7 percent of the average annual flow to as much as 80-90 percent during drought periods, most surface water augmentation indirect potable reuse projects have been driven by requirements for wastewater disposal and pollution control. Their contributions to increased public water supply were incidental. In a comprehensive, comparative study of the Occoquan and Clayton County projects, the water quality parameters assessed were primarily those germane to wastewater disposal and not to drinking water (Reed and Bastian, 1991). Most discharges that contribute to indirect potable water reuse, especially via rivers, are managed as wastewater disposal functions and are handled in conformity with practices common to all water pollution control efforts. The abstraction and use of reclaimed water is almost always the responsibility of a water supply agency that is not related politically, administratively, or even geographically to the wastewater disposal agency (except for being downstream). Increasing populations and a growing scarcity of new water sources have spurred a small but growing number of communities to consider the use of highly-treated municipal wastewater to augment raw water supplies. This trend toward planned, indirect potable reuse is motivated by need, but made possible through advances in treatment technology. These advances enable production of reclaimed water to almost any desired quality. Planned, indirect potable reuse via surface water augmentation and groundwater recharge is being practiced in the U.S. and elsewhere. Notwithstanding the fact that some proposed, high profile, indirect potable reuse projects have been defeated in recent years due to public or political opposition to perceived health concerns, indirect potable reuse will likely increase in the future.

2.6.3 Groundwater Recharge for Indirect Potable Reuse

As mentioned in Section 2.5.1, Methods of Groundwater Recharge, groundwater recharge via surface spreading or injection has long been used to augment potable aquifers. Although both planned and unplanned recharge into potable aquifers has occurred for many years, few health-related studies have been undertaken. The most comprehensive health effects study of an existing groundwater recharge project was carried out in Los Angeles County, California, in response to uncertainties about the health consequences of recharge for potable use raised by a California Consulting Panel in 1975-76.

In November 1978, the County Sanitation Districts of Los Angeles County (Districts) initiated the "Health Effects Study," a $1.4-million-project designed to evaluate the health effects of using treated wastewater for groundwater recharge based on the recommendations of the 1976 Consulting Panel. The focus of the study was the Montebello Forebay Groundwater Replenishment Project, located within the Central Groundwater Basin in Los Angeles County, California. Since 1962, the Districts' reclaimed water has been blended with imported river water (Colorado River and State Project water) and local stormwater runoff, and used for replenishment purposes. The project is managed by the Water Replenishment District of Southern California (WRD) and is operated by the Los Angeles County Department of Public Works. The Central Groundwater Basin is adjudicated; 85 groundwater agencies operate over 400 active wells. Water is percolated into the groundwater using 2 sets of spreading grounds: (1) the Rio Hondo Spreading Grounds consist of 570 acres (200 hectares) with 20 individual basins and (2) the San Gabriel River Spreading Grounds consist of 128 acres (52 hectares) with 3 individual basins and portions of the river. The spreading basins are operated under a wetting/drying cycle designed to optimize inflow and discourage the development of vectors.

From 1962 to 1977, the water used for replenishment was disinfected secondary effluent. Filtration (dual-media or mono-media) was added later to enhance virus inactivation during final disinfection. By 1978, the amount of reclaimed water spread averaged about 8.6 billion gallons per year (33 x 10^3 m^3 per year) or 16 percent of the total inflow to the groundwater basin with no more than about 10.7 billion gallons (40 million m^3) of reclaimed water spread in any year. The percentage of reclaimed water contained in the extracted potable water supply ranged from 0 to 11 percent on a long-term (1962-1977) basis (Crook *et al.,* 1990).

The primary goal of the Health Effects Study was to provide information for use by health and regulatory authorities to determine if the use of reclaimed water for the Montebello Forebay Project should be maintained at the present level, cut back, or expanded. Specific objectives were to determine if the historical level of reuse had adversely affected groundwater quality or human health, and to estimate the relative impact of the different replenishment sources on groundwater quality. Specific research tasks included:

- Water quality characterizations of the replenishment sources and groundwater in terms of their microbiological and chemical content.
- Toxicological and chemical studies of the replenishment sources and groundwater to isolate and identify organic constituents of possible health significance
- Field studies to evaluate the efficacy of soil for attenuating chemicals in reclaimed water
- Hydrogeologic studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies
- Epidemiologic studies of populations ingesting reclaimed water to determine whether their health characteristics differed significantly from a demographically similar control population

During the course of the study, a technical advisory committee and a peer review committee reviewed findings and interpretations. The final project report was completed in March, 1984 as summarized by Nellor *et al.* in 1985. The results of the study did not demonstrate any measurable adverse effects on either the area groundwater or health of the people ingesting the water. Although the study was not designed to provide data for evaluating the impact of an increase in the proportion of reclaimed water used for replenishment, the results did suggest that a closely monitored expansion could be implemented.

In 1986, the State Water Resources Control Board, Department of Water Resources and Department of Health Services established a Scientific Advisory Panel on Groundwater Recharge to review the report and other pertinent information. The Panel concluded that it was comfortable with the safety of the product water and the continuation of the Montebello Forebay Project. The Panel felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters.

Based on the results of the Health Effects Study and recommendations of the Scientific Advisory Panel, the Regional Water Quality Control Board in 1987 authorized an increase in the annual quantity of reclaimed water to be used for replenishment from 32,700 acre-feet per year to 50,000 acre-feet per year (20,270 gpm to 31,000 gpm or 1,280 to 1,955 l/s). In 1991, water reclamation requirements for the project were revised to allow for recharge up to 60,000 acre-feet per year (37,200 gpm or 2,350 l/s) and 50 percent reclaimed water in any one year as long as the running 3-year total did not exceed 150,000 acre-feet per year (93,000 gpm or 5,870 l/s) or 35 percent reclaimed water. The average amount of reclaimed water spread each year is about 50,000 acre-feet per year (31,000 gpm or 1,955 l/s). Continued evaluation of the project is being provided by an extensive sampling and monitoring program, and by supplemental research projects pertaining to percolation effects, epidemiology, and microbiology.

The Rand Corporation has conducted additional health studies for the project as part of an ongoing effort to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.,* 1996 and Sloss *et. al.*, 1999). These studies looked at health outcomes for 900,000 people in the Central Groundwater Basin who are receiving some reclaimed water in their household water supplies. These people account for more than 10 percent of the population of Los Angeles County. To compare health characteristics, a control area of 700,000 people that had similar demographic and socioeconomic characteristics was selected, but did not receive reclaimed water. The results from these studies have found that, after almost 30 years of groundwater recharge, there is no association between reclaimed water and higher rates of cancer, mortality, infectious disease, or adverse birth outcomes.

The Districts, along with water and wastewater agencies and researchers in 3 western states, are currently conducting research to evaluate the biological, chemical, and physical treatment processes that occur naturally as the reclaimed water passes through the soil on the way to the groundwater. The SAT Project was developed to better understand the impact of SAT on water quality in terms of chemical and microbial pollutants (see Case Study 2.7.16). This work will continue to address emerging issues such as the occurrence and significance of pharmaceutically active compounds (including endocrine disruptors and new disinfection byproducts) and standardized monitoring techniques capable of determining pathogen viability. The Groundwater Replenishment (GWR) System is an innovative approach to keeping the Orange County, California, groundwater basin a reliable source for meeting the region's future potable water needs (Chalmers *et al.,* 2003). A joint program of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD), the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County Groundwater Basin (see Case Study 2.7.15).

2.6.4 Direct Potable Water Reuse

Direct potable reuse is currently practiced in only one city in the world, Windhoek, Namibia. This city uses direct potable reuse on an intermittent basis only. In the U.S., the most extensive research focusing on direct potable reuse has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California. A considerable investment in potable reuse research has been made in Denver, Colorado, over a period of more than 20 years. This research included operation of a 1-mgd (44-l/s) reclamation plant in many different process modes over a period of about 10 years (Lauer, 1991). The product water was reported to be of better quality than many potable water sources in the region. The San Diego Total Resource Recovery Project was executed to demonstrate the feasibility of using natural systems for secondary treatment with subsequent advanced wastewater treatment to provide a water supply equivalent or better than the quality of imported water supplied to the region (WEF/AWWA, 1988). **Tables 2-11** and **2-12** show the advanced wastewater treatment effluent concentrations of minerals, metals, and trace organics for the San Diego Project.

Microbial analysis performed over a 2.5-year period, showed that water quality of advanced wastewater treatment effluent was low in infectious agents. Specifically, research showed:

- Spiking studies were conducted to determine the removal level of viruses. Results of 4 runs showed an overall virus removal rate through the primary, secondary, and advanced wastewater treatment plants of between 99.999 9 percent and 99.999 99 percent. Levels of removal were influenced by the number of viruses introduced. Viruses were not detected in more than 20.2 x 10^4 l of sample.

- Enteric bacterial pathogens (that is, *Salmonella, Shigella,* and *Campylobacter*) were not detected in 51 samples of advanced wastewater treatment effluent.

- Protozoa and metazoa of various types were absent in the advanced wastewater treatment effluent. *Giardia lamblia* were not recovered, and based on recovery rates of cysts from raw wastewater, removal rates were estimated to be 99.9 percent (WEF/AWWA, 1998)

The treatment train operated in San Diego, after secondary treatment, includes the following processes:

- Coagulation with ferric chloride
- Multimedia filtration
- Ultraviolet disinfection
- pH adjustment with sulfuric acid
- Cartridge filter
- Reverse osmosis

Most of these unit processes are well understood. Their performance can be expected to be effective and reliable in large, well-managed plants. However, the heavy burden of sophisticated monitoring for trace contaminants that is required for potable reuse may be beyond the capacity of smaller enterprises.

The implementation of direct, pipe-to-pipe, potable reuse is not likely to be adopted in the foreseeable future in the U.S. for several reasons:

- Many attitude (opinion) surveys show that the public will accept and endorse many types of nonpotable reuse while being reluctant to accept potable reuse. In general, public reluctance to support reuse in-

Table 2-11. Physical and Chemical Sampling Results from the San Diego Potable Reuse Study

Constituents	Number of Samples	Units	Minimum Detection Limit	Number of Samples < MDL	Arithmetic Mean	Standard Deviation	90th Percentile
General							
COD	611	mg/L	15	6	<15.0	44.8[a]	2.7
pH	892	—	na	892	8.2	0.2	—
SS	116	mg/L	1	68	1.6	3.5	5.6
TOC	611	mg/L	1	85	<1.0	3.0[a]	1.1
Anions							
Chloride	97	mg/L	4	96	33.93	31.39	81.1
Fluoride	37	mg/L	0.13	13	<0.125	0.33[a]	0.241
Ammonia	71	mg/L	0.1	69	1.26	2.04	2.92
Nitrite	37	mg/L	0.01	13	<0.01	0.05[a]	0.03
Nitrate	91	mg/L	0.05	91	1.81	1.21	5.77
Phosphate	88	mg/L	1	28	<1.00	2.70[a]	2.2
Silicate	39	mg/L	0.2	39	1.2	0.42	1.83
Sulfate	96	mg/L	0.1	96	6.45	5.72	14.6
Cations							
Boron	24	mg/L	0.1	24	0.24	0.085	0.368
Calcium	21	mg/L	1	16	3.817	12.262	3.87
Iron	21	mg/L	0.01	20	0.054	0.077	0.135
Magnesium	21	mg/L	0.5	16	1.127	6.706	7.89
Manganese	21	mg/L	0.008	18	0.011	0.041	0.042
Potassium	21	mg/L	0.5	14	0.608	2.599	3.42
Sodium	21	mg/L	1	20	16.999	15.072	54.2
Zinc	20	mg/L	0.005	15	0.009	0.008	0.02

[a] Analysis gave negative result for mean.
Source: WEF/AWWA, 1998.

Table 2-12. San Diego Potable Reuse Study: Heavy Metals and Trace Organics Results

Constituents	Number of Samples	Units	Minimum Detection Limit[a]	Number of Samples > MDL	Arithmetic Mean	Standard Deviation
Metals						
Arsenic	11	μg/L	1	5	<1	8[b]
Cadmium	10	μg/L	1	1	1	0.3
Chromium	19	μg/L	1	10	2	3
Copper	20	μg/L	6	18	18	20
Lead	18	μg/L	1	15	3	7
Mercury	8	μg/L	1	0	1	0[c]
Nickel	20	μg/L	1.2	19	6	7
Selenium	12	μg/L	6	2	4	3[c]
Silver	16	μg/L	5	2	3	4
Organics						
Bis (2-ethyl hexyl phthalate)	33	μg/L	2.5	6	<2.50	3.27[b]
Benzyl/butyl phthalate	33	μg/L	2.5	1	2.5	0.02[c]
Bromodichloromethane	33	μg/L	3.1	0	3.1	0.00[c]
Chloroform	33	μg/L	1.6	0	1.6	0.00[c]
Dibutyl phthalate	33	μg/L	2.5	1	2.64	0.78[c]
Dimethylphenol	33	μg/L	2.7	0	2.7	0.00[c]
Methyl chloride	33	μg/L	2.8	6	<2.80	7.91[b]
Naphthalene	33	μg/L	1.6	0	1.6	0
1,1,1 – Trichloroethane	33	μg/L	3.8	0	3.8	0
1,2 – Dichlorobenzene	33	μg/L	4.4	0	4.4	0
4 - Nitrophenol	33	μg/L	2.4	0	2.4	0
Pentachlorophenol	33	μg/L	3.6	0	3.6	0
Phenol	33	μg/L	1.5	0	1.5	0

[a] <MDL was taken to be equal to MDL.

[b] Analysis gave negative result for mean.

[c] Statistics were calculated using conventional formulas.

Source: WEF/AWWA, 1998.

creases as the degree of human contact with reclaimed water increases. Further, public issues have been raised relevant to potential health impacts which may be present in reclaimed water.

- Indirect potable reuse is more acceptable to the public than direct potable reuse, because the water is perceived to be “laundered” as it moves through a river, lake, or aquifer (i.e. the Montebello Forebay and El Paso projects). Indirect reuse, by virtue of the residence time in the watercourse, reservoir or aquifer, often provides additional treatment. Indirect reuse offers an opportunity for monitoring the quality and taking appropriate measures before the water is abstracted for distribution. In some instances, however, water quality may actually be degraded as it passes through the environment.

- Direct potable reuse will seldom be necessary. Only a small portion of the water used in a community needs to be of potable quality. While high quality sources will often be inadequate to serve all urban needs in the future, the use of reclaimed water to replace potable quality water for nonpotable purposes will release more high quality potable water for future use.

2.7 Case Studies

The following case studies are organized by category of reuse applications:

Urban	Sections 2.7.1 through 2.7.6
Industrial	Sections 2.7.7 through 2.7.8
Agricultural	Sections 2.7.9 through 2.7.12
Environmental and Recreational	Section 2.7.13
Groundwater Recharge	Section 2.7.14 through 2.7.16
Augmentation of Potable Supplies	Section 2.7.17
Miscellaneous	Section 2.7.18 through 2.7.19

2.7.1 Water Reuse at Reedy Creek Improvement District

Reedy Creek Improvement District (RCID) provides municipal services to the Walt Disney World Resort Complex, located in Central Florida. In 1989, RCID faced a challenge of halting inconsistent water quality discharges from its wetland treatment system. The solution was a twofold approach: (1) land was purchased for the construction of rapid infiltration basins (RIBs) and (2) plans were drafted for the construction of a reuse distribution system. The RIBs were completed in 1990. Subsequently, all surface water discharges ceased. The RIBs recharge the groundwater via percolation of applied effluent to surficial sands and sandy clays. Eighty–five 1-acre basins were built and operate on a 6 to 8 week rotational cycle. Typically, 10 or 11 basins are in active service for a 1-week period; while the remaining basins are inactive and undergo maintenance by discing of the bottom sands. Initially, the RIBs served as the primary mechanism for reuse and effluent disposal, receiving 100 percent of the effluent. But the trend has completely reversed in recent years, and the RIBs serve primarily as a means of wet-weather recharge or disposal of sub-standard quality water. The majority of the effluent is used for public access reuse. In the past 3 years, over 60 percent of the effluent volume was used for public access reuse.

Initially, the reclaimed water distribution system served 5 golf courses and provided some landscape irrigation within RCID. In the past 10 years, the extent and diversity of uses has grown and now includes washdown of impervious surfaces, construction (such as concrete mixing and cleanup), cooling tower make up, fire fighting (suppression and protection), irrigation of all types of vegetation and landscaping, and all of the nonpotable needs for clean water within the treatment facility.

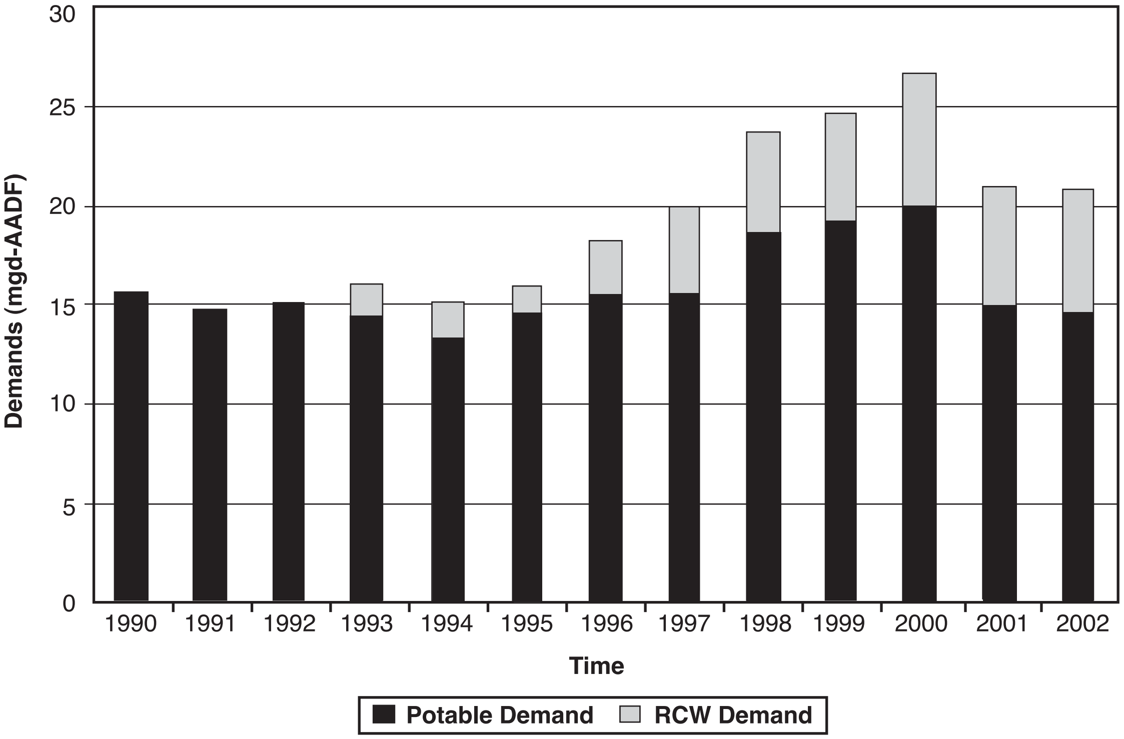
All product water bound for the reuse system is metered. There is a master meter at the master pumping station, and all customers are metered individually at the point of service. Rates are typically set at 75 to 80 percent of the potable water rate to encourage connection and use. Rates are based on volumetric consumption to discourage wasteful practices. New customers are required by tariff to connect to and use the reclaimed water system. If the system is not available, new customers are required to provide a single point of service to facilitate future connection. Existing customers using potable water for nonpotable purposes are included in a master plan for future conversion to reclaimed water.

Demands for reclaimed water have sometimes exceeded supply capabilities, especially during the months of April and May, when rainfall is lowest and demand for irrigation is at its highest. RCID has a number of means at its disposal to counteract this shortfall. The primary means uses 2, formerly idle, potable water wells to supplement the reclaimed water systems during high demand. These wells can provide up to 5,000 gpm (315 l/s) of additional supply. A secondary means requests that major, selected customers return to their prior source of water. Two of the golf courses can return to surface waters for their needs and some of the cooling towers can be quickly converted to potable water use (and back again).

Total water demand within RCID ranges from 18 to 25 mgd (180 to 1,100 l/s) for potable and nonpotable uses. Reclaimed water utilization accounts for 25 to 30 percent of this demand. Over 6 mgd (260 l/s) is typically consumed on an average day and peak day demands have exceeded 12 mgd (525 l/s). Providing reclaimed water for nonpotable uses has enabled RCID to remain within its consumptive use permit limitations for groundwater withdrawal, despite significant growth within its boundaries. Reclaimed water has been a major resource in enabling RCID to meet water use restrictions imposed by the water management districts in alleviating recent drought impacts. **Figure 2-9** is a stacked bar graph that shows the historical contribution reclaimed water has made to the total water resource picture at RCID.

The continued growth of the RCID reclaimed water system is expected to play an ever-increasing and critical role in meeting its water resource needs. Because alternative sources of water (e.g., surface water, brackish water, and stormwater) are not easily and reliably available and are prohibitively costly to obtain, it makes eco-

Figure 2-9. **Water Resources at RCID**



nomic sense for RCID to maximize its use of reclaimed water.

2.7.2 Estimating Potable Water Conserved in Altamonte Springs due to Reuse

It is taken for granted that implementing a reclaimed water system for urban irrigation will conserve potable water, but few efforts have been made to quantify the benefits. An analysis was performed to define the potential value of urban reuse for a moderately sized city, Altamonte Springs, Florida. Altamonte Springs began implementing its reclaimed water system in 1990.

First, annual potable water-use data were analyzed to ascertain if a significant difference could be seen between periods before and after reuse. **Figure 2-10** shows the historical potable water demands from 1977 to 2000, expressed as gallons of water used per capita per day.

Figure 2-10 indicates a much greater potable water demand before reuse was implemented than after. In 1990, the demand dropped by about 20 gallons per capita-day (76 liters per capita-day) in just one year.

Two differing methods were used to estimate the total potable water conserved through implementing a reclaimed water system. The first method, a linear extrapolation model (LEM), assumes that the rate of increasing water use per capita for 1990 to 2000 increases as it did from 1977 to 1989. Then, the amount conserved per year can be estimated by taking the difference in the potential value from the linear model and the actual potable water used. **Figure 2-11** predicts the amount of potable water saved by implementing the reuse system from 1990 to 2000.

The other method used a more conservative, constant model (CCM). This model averages the gallons of potable water per capita-day from the years before reuse and assumes that the average is constant for the years after reuse. **Figure 2-12** indicates this model's estimate of potable water conserved.

In the year 2000, the LEM model estimates that 102 gallons per capita-day (386 liters per capita-day) of potable water are saved. In the same year, the CCM method estimates a net savings of 69 gallons per capita-day. **Figure 2-13** shows the comparison of the amount conserved using the 2 different methods.

2.7.3 How Using Potable Supplies to Supplement Reclaimed Water Flows can Increase Conservation, Hillsborough County, Florida

Ensuring that an adequate source is available is one of the first steps in evaluating a potable water project. However, consideration of how many reclaimed water customers can be supplied by the flows from a water reclamation facility is seldom part of the reuse planning process. The problem with this approach has become apparent in recent years, as a number of large urban reuse systems have literally run out of water during peak reclaimed water demand times.

In order to understand why this happens, it is important to understand the nature of demands for reclaimed water. **Figure 2-14** illustrates expected seasonal reclaimed water demands for irrigation in southwest Florida. Every operator of a potable water system in this area expects demands to increase by 20 to 30 percent during April through June as customers use drinking water to meet peak season irrigation demands. For reclaimed water systems, which are dedicated to meeting urban irrigation demands, the peak season demands may increase by 50 to 100 percent of the average annual demand. It is, of course, the ability to meet these peak season demands that define the reliability of a utility system, including a reclaimed water system.

How Augmentation Can Help

While peak season demand is what limits the number of customers a utility can connect, it is also short lived, lasting between 60 to 90 days. Augmenting reclaimed water supplies during this time of peak demand can allow a municipality to increase the number of customers served with reclaimed water while preserving the reliability (level of service) of the system. To illustrate this point, consider the Hillsborough County South/Central reclaimed water system. Reclaimed water supplies from the Falkenburg, Valrico, and South County Water Reclamation Facilities (WRFs) are expected to be an annual average of 12.67 mgd (555 l/s) in 2002. However, to avoid shortfalls in the peak demand season, the County will need to limit connections to an average annual demand of 7.34 mgd (321 l/s) or less. The County presently has a waiting list of customers that would demand an annual average of approximately 10.69 mgd (468 l/s). What if augmentation water were used to allow the County to connect these customers instead of making these customers wait? Water balance calculations indicate that from July through March, there will be more than enough reclaimed water to meet expected demands. However, in April, May, and June, reclaimed water demands will exceed available supplies and customers will experience shortages. Using a temporary augmentation supply of water could offset these shortages during this 60 to 90 day period.

Figure 2-10. Altamonte Springs Annual Potable Water Demands per Capita

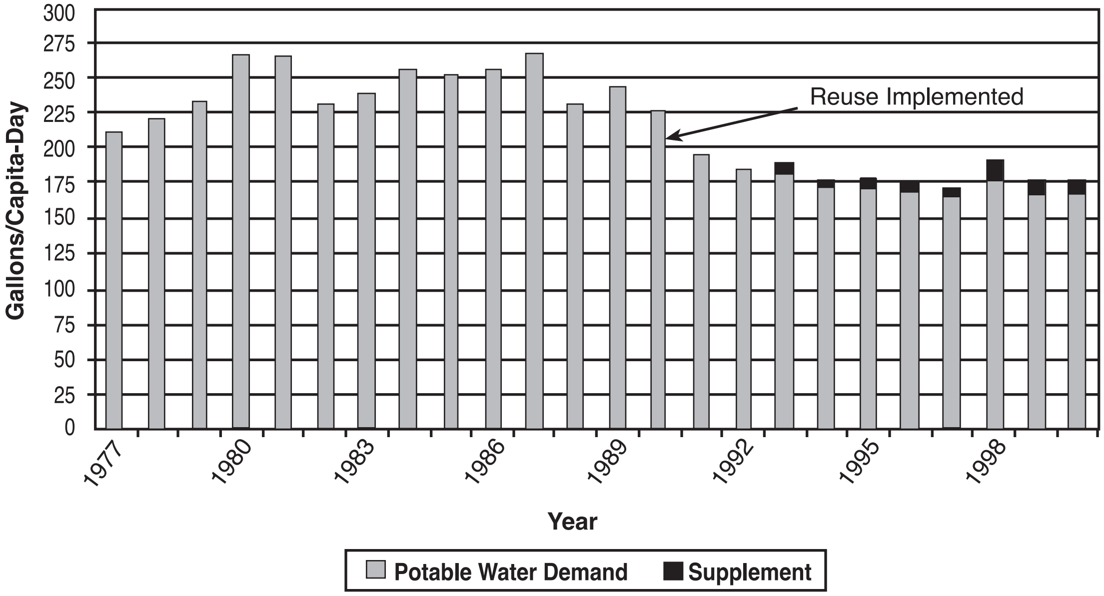


Figure 2-11. Estimated Potable Water Conserved Using Best LEM Method

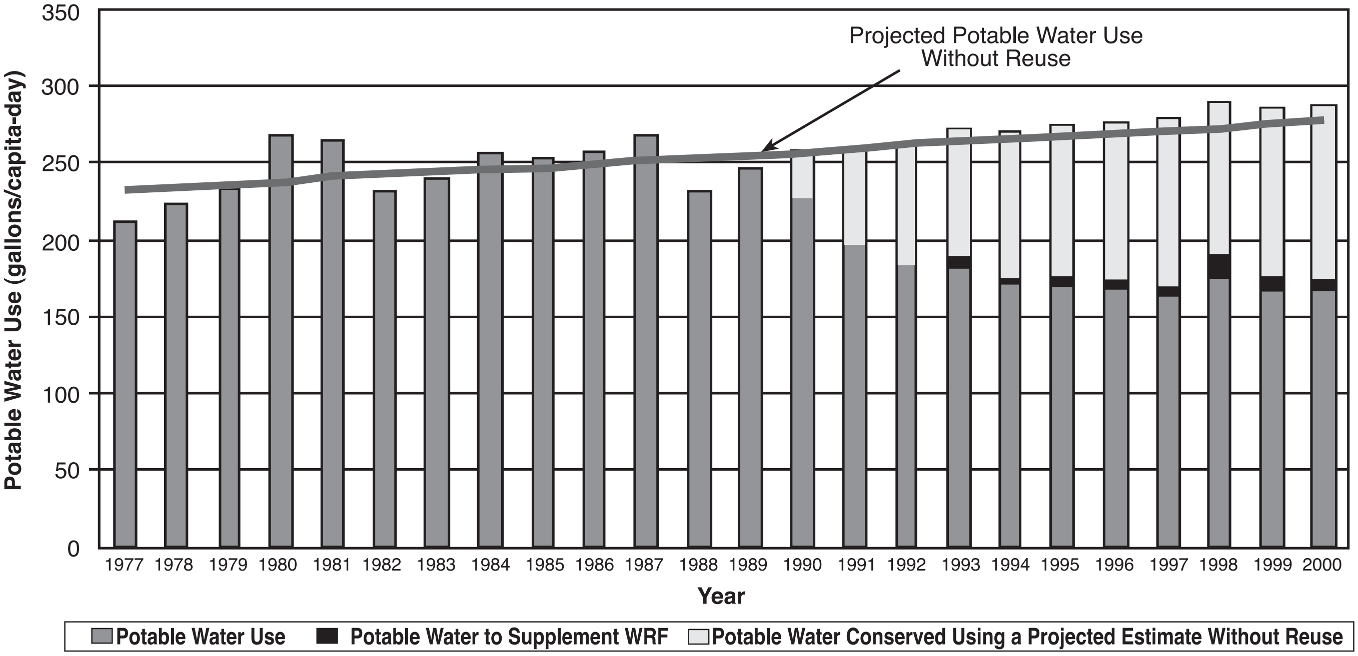


Figure 2-12. Estimated Potable Water Conserved Using the CCM Method

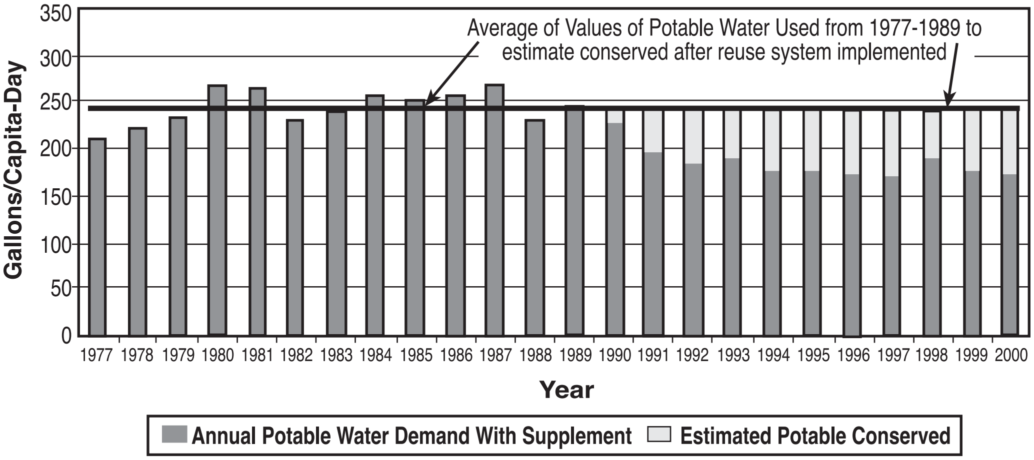


Figure 2-13. Estimated Potable Water Conserved Using Both Method

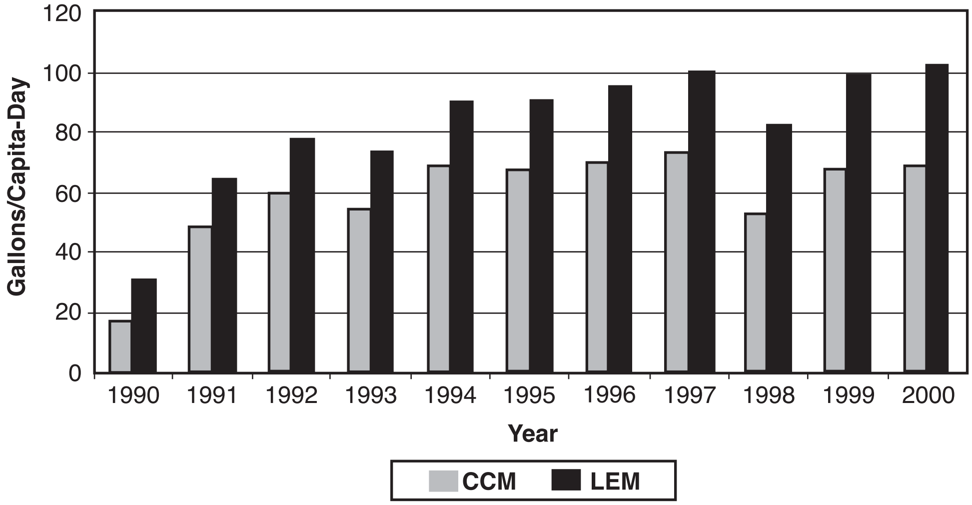


Figure 2-14. Estimated Raw Water Supply vs. Demand for the 2002 South/Central Service Area

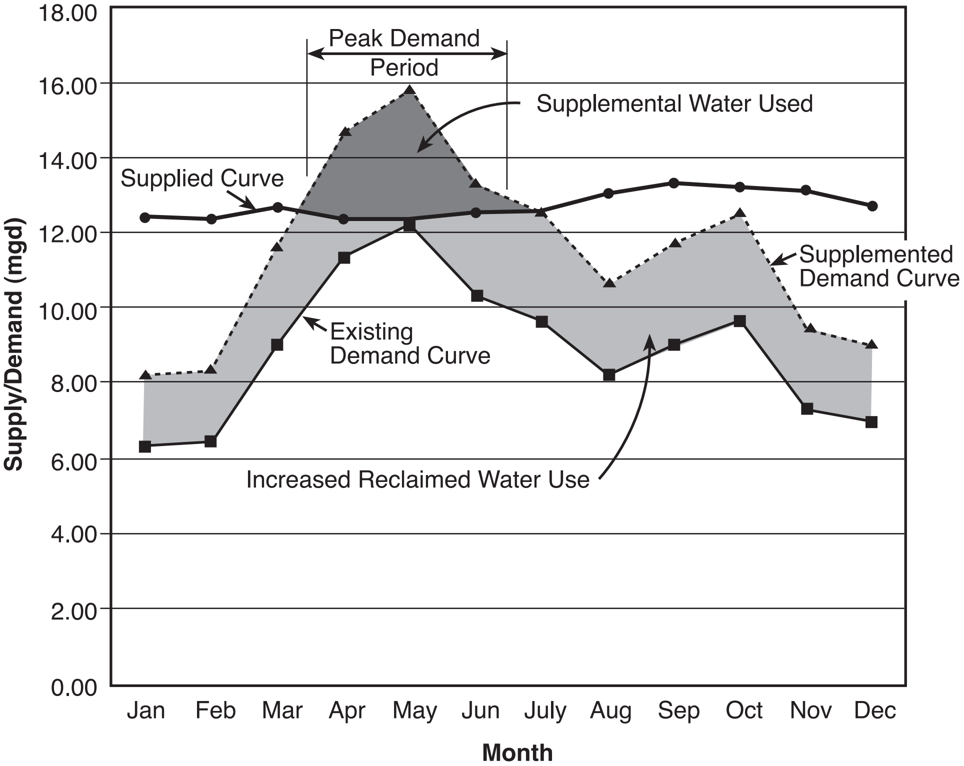


Figure 2-14 illustrates the expected seasonal supply curve for 2002. The bottom curve shows the expected demand for the limited case where the County does not augment its water supplies. The top curve indicates how the County can meet current demand by augmenting its reclaimed water supply during April through June. The limited reclaimed water system is constrained by peak seasonal demands (not exceeding supply) since customers expect year round service. For the system to meet all of the potential demands that have been identified, sufficient reclaimed water augmentation must be used to make up the differences in supply and demand.

The obvious question that must be answered is, “Can using supplemental water actually conserve water resources?” The answer is yes, to a point. The existing, limited reuse system serves an average annual demand of 7.34 mgd (321 l/s), conserving an annual average of 6.07 mgd (266 l/s) of potable water resources. This level of conservation is based on the County’s experiences with reductions in potable water demand after reclaimed water becomes available. In order to provide service to the entire 10.69 mgd (468 l/s) reclaimed water demand, the County will need an average annual supply of supplemental water of 0.5 mgd (22 l/s). For the purposes of this analysis, it is assumed this supplemental water comes from the potable water system and so is subtracted from the “Annual Average Potable Water Conserved.” This 0.5 mgd potable water supplemental supply increases the total volume of water conserved from 6.07 to 7.23 mgd (266 to 321 l/s). Therefore, 1.16 mgd (51 l/s) more potable water is conserved by using supplemental water. Therefore, an investment of 0.5 mgd (22 l/s) of supplemental water allows the County to save 1.16 mgd (51 l/s) of potable water resources or, put another way, for each gallon (3.8 liters) of supplemental water used we realize a 2.32-gallon (8.8-liter) increase in water resources conserved. There are, of course, limitations to this practice. As more supplemental water is used, the amount of reclaimed water used (as a percentage of the total demand) decreases. Eventually, the supplemental water used will be equal to the water resources conserved. That is the break-even point. In this case potable water was used as the supplemental water, but in reality, other nonpotable supplies, such as raw groundwater, would likely be used.

Short-term supplementation, such as that described above, is one of many tools that can be used by a reclaimed water provider to optimize its system. Utilities can also maximize their existing reclaimed water resources and increase efficiency by instituting Best Management Practices (BMPs). Examples of BMPs include individual metering, volume-based, water-conserving rate structures, planned interruption, peak season “interruptible service”, and time-of-day and day-of-week restrictions. When a reclaimed water provider is already experiencing either a long-term supply/demand imbalance or temporary drought effects, that provider should first use BMPs, before considering reclaimed water supplementation. Utilities should also investigate opportunities for enhanced reclaimed water storage capacity including innovative technological solutions, such as aquifer storage and recovery, and wet-weather discharge points that produce a net environmental benefit. Instituting BMPs and the other options mentioned can enable a reclaimed water utility to delay, lessen, or potentially eliminate the need for augmentation of their reclaimed water system during peak reclaimed water demand periods.

2.7.4 Water Reclamation and Reuse Offer an Integrated Approach to Wastewater Treatment and Water Resources Issues in Phoenix, Arizona.

The rapidly developing area of North Phoenix is placing ever-increasing demands on the city’s existing wastewater collection system, wastewater treatment plants, and potable water resources. As an integrated solution to these issues, water reclamation and reuse have become an important part of Phoenix Water Services Department’s operational strategy.

Cave Creek Reclaimed Water Reclamation Plant (CCWRP), in northeast Phoenix, began operation in September 2001. The facility uses an activated sludge nitrification/denitrification process along with filtration and ultraviolet light disinfection to produce a tertiary-grade effluent that meets the Arizona Department of Environmental Quality’s A+ standards. CCWRP is currently able to treat 8 mgd (350 l/s) and has an expansion capacity of 32 mgd (1,400 l/s).

The Phoenix reclamation plant delivers reclaimed water through a nonpotable distribution system to golf courses, parks, schools, and cemeteries for irrigation purposes. The reclaimed water is sold to customers at 80 percent of the potable water rate.

CCWRP’s sister facility, North Gateway Water Reclamation Plant (NGWRP), will serve the northwest portion of Phoenix. The design phase has been completed. The NGWRP will have an initial treatment capacity of 4 mgd (175 l/s) with an ultimate capacity of 32 mgd (1,400 l/s). The plant is modeled after the Cave Creek facility using the “don’t see it, don’t hear it, don’t smell it” design mantra. Construction will be preformed using the construction manager-at-risk delivery method.

Phoenix is using geographic information system (GIS) technology to develop master plans for the buildout of the reclaimed water distribution system for both the Cave Creek and North Gateway reclamation plants. Through GIS, potential reclaimed water customers are easily identified. GIS also provides information useful for determining pipe routing, reservoir, and pump station locations. The goal is to interconnect the 2 facilities, thus building more reliability and flexibility into the system. The GIS model is dynamically linked to the water system, planning, and other important databases so that geospacial information is constantly kept up to date. A hydraulic model is being used in conjunction with the GIS model to optimize system operation.

Irrigation demand in Phoenix varies dramatically with the seasons, so groundwater recharge and recovery is a key component of the water reuse program. Phoenix is currently exploring the use of vadose zone wells because they do not require much space and are relatively inexpensive to construct. This method also provides additional treatment to the water as it percolates into the aquifer. A pilot vadose zone well facility has been constructed at the NGWRP site to determine the efficacy of this technology. A vadose zone recharge facility along with a recovery well is being designed for the CCWRP site.

Nonpotable reuse and groundwater recharge with high quality effluent play an important role in the City's water resources and operating strategies. The North Phoenix Reclaimed Water System (**Figure 2-15**) integrates multiple objectives, such as minimizing the impact of development in the existing wastewater infrastructure by treating wastewater locally and providing a new water resource in a desert environment. By using state-of-the-art technology, such as GIS, Phoenix will be able to plan the buildout of the reclaimed water system to maximize its efficiency and minimize costs.

2.7.5 Small and Growing Community: Yelm, Washington

The City of Yelm, Washington, a community of 3,500 residents, is considered one of western Washington's fastest growing cities. In response to a determination from Thurston County that the continued use of septic systems in the Yelm area posed a risk to public health, the City developed a sewage plan. The original plan was to treat and discharge wastewater to the Nisqually River. However, the headwaters of the Nisqually River begin in Mount Rainier National Park and end in a National Wildlife Refuge before discharging into the Puget Sound Estuary. The river supports 5 species of Pacific salmon—chinook, coho, pink, chum, and steelhead—as well as sea-run cutthroat trout. Based on a settlement agreement with local environmental groups, the City agreed to pursue upland reuse of their Class A reclaimed water with the goal of eliminating the Nisqually River as a wastewater discharge location to augment surface water bodies only during times when reclaimed water could not be used 100 percent upland. Reclaimed water also plays a very important role in water conservation as Yelm has limited water resources.

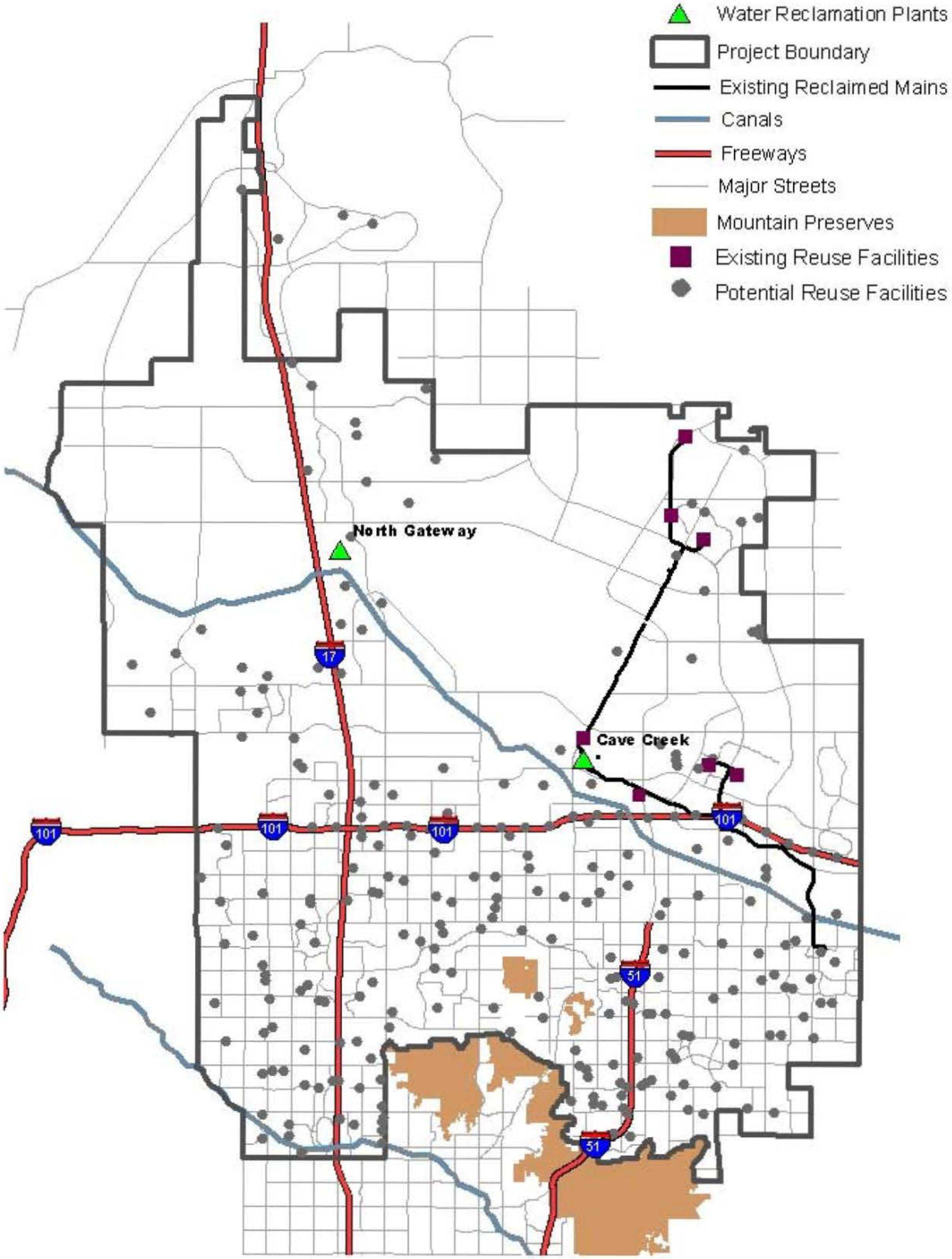
The reclamation plant went on line in August of 1999 and currently reclaims and reuses approximately 230,000 gpd (871 m^3/d). The facility has a design capacity to reclaim up to 1.0 mgd (44 l/s). State standards require the use of treatment techniques for source control, oxidation, coagulation, filtration, and disinfection. Final reclaimed water requirements include a daily average turbidity of less than 2.0 NTU with no values above 5.0 NTU, total coliform less than 2.2 per 100 ml as a 7-day median value and total nitrogen below 10 mg/l. Major facility components include a septic tank effluent pumping (STEP) collection system, activated sludge biological treatment with nitrogen removal using Sequencing Batch Reactor (SBR) technology, flow equalization, an automated chemical feed system with in-line static mixers to coagulate remaining solids prior to filtration, a continuous backwash, upflow sand media filtration system, and chlorine disinfection. The facility also includes an on-line computer monitoring system. Process monitors provide continuous monitoring of flow, turbidity, and chlorine residual. Alarms provide warning when turbidity reaches 2.0 NTU, the flow to the filters shuts off at 3.0 NTU, and the intermediate pumps shut down at 3.5 NTU. Chlorine concentrations are set for an auto-dialer alarm if the flash mixer falls below 1.5 mg/l or if the final residual is below 0.75 mg/l. Only reclaimed water that meets the required standard is sent to upland use areas.

Reclaimed water in Yelm is primarily used for seasonal urban landscape irrigation at local schools and churches, city parks, and a private residence along the distribution route. The true showcase of the Yelm project is Cochrane Memorial Park, an aesthetically pleasing 8-acre city park featuring constructed surface and submerged wetlands designed to polish the reclaimed water prior to recharging groundwater. In the center of the park, a fishpond uses reclaimed water to raise and maintain stocked rainbow trout for catch and release. The City also uses reclaimed water for treatment plant equipment washdown and process water, fire fighting, street cleaning, and dust control.

Although summers in western Washington are quite dry, during the winter rainy season there is not sufficient irrigation demand for reclaimed water. Excess water is sent to generate power in the Centralia Power Canal, a diversion from the Nisqually River. Based on state law, reclaimed water that meets both the reclamation standards and state and federal surface water quality requirements is "no longer considered a wastewater." However, per their settlement agreement, Yelm is continuing to pursue the goal of 100 percent upland reuse via a program to add reclaimed water customers and uses.

Yelm recently updated its Comprehensive Water Plan to emphasize an increased dependence on reclaimed water to replace potable water consumption to the greatest

Figure 2-15. North Phoenix Reclaimed Water System



extent possible. The City is constructing storage capacity to provide collection of reclaimed water during non-peak periods for distribution during periods of peak demand. This will allow more efficient use of reclaimed water and eliminate the need for potable make-up water. Yelm is planning to use reclaimed water for bus washing, concrete manufacturing, and additional irrigation purposes.

Sources: Washington State Department of Ecology and City of Yelm, 2003.

2.7.6 Landscape Uses of Reclaimed Water with Elevated Salinity: El Paso, Texas

Because of declining reserves of fresh groundwater and an uncertain supply of surface water, the Public Service Board, the governing body of El Paso Water Utilities, has adopted a strategy to curtail irrigation use of potable water by substituting reclaimed municipal effluent. This strategy has been implemented in stages, starting with irrigation of a county-operated golf course using secondary effluent from the Haskell Plant, and a city-owned golf course with tertiary treated effluent from the Fred Hervey Plant. More recently, the reuse projects were expanded to use secondary effluent from the Northwest Plant to irrigate a private golf course, municipal parks, and school grounds (Ornelas and Brosman, 2002). Reclaimed water use from the Haskell Plant is also being expanded to include parks and school grounds.

Salinity of reclaimed water ranges from 680 to 1200 ppm as total dissolved salts (TDS) depending on the plant (Table 2-13). Reclaimed water from the Hervey Plant has the lowest salinity (680 ppm), and a large portion of it is now being injected into an aquifer for recovery as potable water. Reclaimed water from the Haskell Plant and the Northwest plant have elevated levels of salinity, and are likely to be the principal reclaimed sources for irrigation from now into the near future. The cause of elevated salinity at the Northwest Plant is currently being investigated, and it appears to be related to intrusion of shallow saline groundwater into sewer collection systems located in the valley where high water tables prevail.

Reuse of reclaimed water from the Hervey Plant on a golf course proceeded without any recognizable ill effects on turf or soil quality. This golf course is located on sandy soils developed to about 2 feet (60 cm) over a layer of caliche, which is mostly permeable. Broadleaf trees have experienced some foliar damage, but not to the extent of receiving frequent user complaints. This golf course uses low pressure, manual sprinklers, and plantings consist mostly of pines, which are spray resistant. Reuse of reclaimed water from the Northwest Plant, however, has caused severe foliar damage to a large number of broadleaf trees (Miyamoto and White, 2002). This damage has been more extensive than what was projected based on the total dissolved salts of 1200 ppm. However, this reclaimed water source has a Na concentration equal to or higher than saline reclaimed water sources in this part of the Southwest (**Table 2-13**). Foliar damage is caused primarily through direct salt adsorption through leaves. This damage can be minimized by reducing direct sprinkling onto the tree canopy. The use of low-trajectory nozzles or sprinklers was found to be

Table 2-13. Average Discharge Rates and Quality of Municipal Reclaimed Effluent in El Paso and Other Area Communities

Treatment Plants	Plant Capacity (mgd)	Reuse Area (acres)	Water Quality					Soil Type
			TDS (ppm)	EC (dS m^{1})	SAR	Na (ppm)	Cl (ppm)	
El Paso								
Fred Hervey	10	150	680	0.9	3.7	150	180	Calciorthid, Aridisols
Haskell	27	329	980	1.6	7.3	250	280	Torrifluvent, Entisols
Northwest	17	194	1200	2.2	11.0	350	325	Paleorthid, Aridisols
Alamogordo[1]	--	--	1800	2.7	2	310	480	Camborthid, Aridisols
Odessa[2]	--	--	1650	2.4	1.9	330	520	Paleustal, Alfisols

[1] These water sources contain substantial quantities of Ca and SO_4.

[2] Reclaimed water quality of this source changes with season.

Sources: Ornela and Brosman, 2002; Miyamoto and White, 2002; Ornelas and Miyamoto, 2003; and Miyamoto, 2003.

effective through a test program funded by the Bureau of Reclamation (Ornelas and Miyamoto, 2003). This finding is now used to contain salt-induced foliar damage.

Another problem associated with the conversion to reclaimed water has been the sporadic occurrence of salt spots on the turf in areas where drainage is poor. This problem has been contained through trenching and subsoiling. Soil salinization problems were also noted in municipal parks and school grounds that were irrigated with potable water in the valley where clayey soils prevail. This problem is projected to increase upon conversion to reclaimed water from the Haskell Plant unless salt leaching is improved. The Texas A&M Research Center at El Paso has developed a guideline for soil selection (Miyamoto, 2003), and El Paso City Parks, in cooperation with Texas A&M Research Center, are initiating a test program to determine cost-effective methods of enhancing salt leaching. Current indications are that increased soil aerification activities, coupled with topdressing with sand, may prove to be an effective measure. If the current projection holds, reuse projects in El Paso are likely to achieve the primary goal, while demonstrating that reclaimed water with high Na and Cl concentrations (greater than 359 ppm) can be used effectively even in highly diverse soil conditions through site improvements and modified management practices.

2.7.7 Use of Reclaimed Water in a Fabric Dyeing Industry

The Central Basin Municipal Water District (CBMWD) reclaimed water system began operation in 1992 and currently serves approximately 3,700 acre-feet per year (2,300 gpm) for a variety of irrigation, commercial, and industrial uses. Industrial customers include the successful conversion of Tuftex Carpets in Santa Fe Springs, which was the first application in California of reclaimed water used for carpet dyeing. A significant benefit to using reclaimed water is the consistency of water quality. This reduces the adjustments required by the dye house that had previously been needed due to varying sources of water (e.g. Colorado River, State Water Project, or groundwater). Since completion of the initial system, CBMWD has continued to explore expansion possibilities, looking at innovative uses of reclaimed water.

The fabric dyeing industry represents a significant potential for increased reclaimed water use in CBMWD and in the neighboring West Basin Municipal Water District (WBMWD). More than 15 dye houses are located within the 2 Districts, with a potential demand estimated to be greater than 4,000 acre-feet per year (2,500 gpm). A national search of reclaimed water uses did not identify any existing use of tertiary treated wastewater in fabric dyeing.

General Dye and Finishing (General Dye) is a fabric dyeing facility located in Santa Fe Springs, California. This facility uses between 400 and 500 acre-feet per year (250 to 310 gpm) of water, primarily in their dye process and for boiler feed. CBMWD is working with the plant manager to convert the facility from domestic potable water to reclaimed water for these industrial purposes.

A 1-day pilot test was conducted on October 15, 2002 using reclaimed water in one of the 12 large dye machines used at the facility. A temporary connection was made directly to the dye machine fill line using a 1-inch hose from an air release valve on the CBMWD reclaimed water system. General Dye conducted 2 tests with the reclaimed water, using reactive dye with a polycotton blend and using dispersed dye with a 100-percent polyester fabric.

Both test loads used about 800 pounds of fabric with blue dyes. The identical means and methods of the dyeing process typically employed by General Dye with domestic water were also followed using reclaimed water. General Dye did not notice any difference in the dyeing process or quality of the end product using the reclaimed water versus domestic water.

A 1-week demonstration test was conducted between November 20 and November 27, 2002, based on the successful results of the 1-day pilot test. A large variety of colors were used during the demonstration test. No other parameters were changed. Everything was done exactly the same with the reclaimed water that would have been done with the domestic water. As with the pilot test, the results indicated that reclaimed water can successfully be used in the fabric dyeing process, resulting in plans for a full conversion of the General Dye facility to reclaimed water for all process water needs.

2.7.8 Survey of Power Plants Using Reclaimed Water for Cooling Water

A wide variety of power facilities throughout the U.S. were contacted and asked to report on their experience with the use of treated wastewater effluent as cooling water. **Table 2-14** presents a tabulation of data obtained from contacts with various power facilities and related wastewater treatment plants that supply them with effluent water. Table 2-14 also provides a general summary of the treatment process for each WWTP and identifies treatment performed at the power plant.

Table 2-14. Treatment Processes for Power Plant Cooling Water

Power Facility & Location	Average Cooling Water Supply & Return Flow (mgd)	Wastewater Treatment Plant Processes	Treatment for Cooling Water (by Power Plant)
1. Lancaster County Resource Recovery Facility Marietta, PA	Supply = 0.65 Return = 0 Zero discharge; all blow-down evaporated or leaves plant in sludge.	Secondary treatment with Alum, Floc & Polymer; Additions settle solids, remove phosphorus	Further treatment with clarification process, Flash Mix, Slow Mix. Also additions of ferric sulfate, polymer & sodium hypochlorite
2. PSE&G Ridgefield Park, NJ	Supply = 0.3 – 0.6 (make-up supply to cooling towers) Blow-down disposed of with plant wastewater to local sewer system.	Secondary Treatment, 85% minimum removal of solids	Water chemistry controlled with biocide, pH control, and surfactant
3. Hillsborough County Solid Waste to Energy Recovery Facility (operated by Ogden Martin Corp.) Tampa, FL	Supply = 0.7 (includes irrigation water) Blow-down of 0.093-mgd mixed with plant wastewater is returned to WWTP.	Advanced treatment with high level of disinfection. Partial tertiary treatment, removes phosphorus.	Chlorine addition, biocide, surfactant, tri-sodium phosphate, pH control with sulfuric acid.
4. Nevada Power – Clark and Sunrise Stations Las Vegas, NV	Supply = 2.72 (annual avg.) to Clark Sta. Return = 0 Blow-down is discharged to holding ponds for evaporation	Advanced Secondary treatment with nitrification, denitrification and biological phosphorus removal. Tertiary treatment through dual media filter & disinfection in chlorine contact tank.	None at present time. Previously treated with lime & softener; discontinued 2-3 years ago.
5. Panda Brandywine Facility Brandywine, MD	Supply = 0.65 Cooling tower blow-down is discharged to a local sewage system and eventually returned to the WWTP.	Primary & secondary settling. Biological nutrient removal, with post filtration via sand filters.	Addition of corrosion inhibitors, sodium hypochlorite, acid for pH control, and anti-foaming agents.
6. Chevron Refineries; El Segundo, CA Richmond, CA	Approx = 3-5 Return = 0	Tertiary treatment El Segundo: Ammonia Stripping plant across street. Richmond: Caustic Soda Treatment Plant Specifically for Chevron.	Richmond Plant uses Nalco Chemical for further treatment.
7. Curtis Stanton Energy Center Orange County, FL (near Orlando)	Supply = 10 Return = 0 Blow-down is evaporated in brine concentrator and crystallizer units at power plant for zero discharge.	Advanced Wastewater treatment including filtration, disinfection & biological nutrient removal to within 5:5:3:1*	PH adjustment with acid, addition of scale inhibitors and chlorine. Control of calcium level. All chemical adjustments done at cooling towers.
8. Palo Verde Nuclear Plant Phoenix, AZ	Total Supply to (3) units = 72 Return = 0 Zero discharge facility; all blow-down is evaporated in ponds.	WWTPs provide secondary treatment. Treated effluent not transmitted to Palo Verde is discharged to riverbeds (wetlands) under State of Arizona permits.	Tertiary treatment plant consisting of trickling filters for ammonia removal, 1st and 2nd stage clarifiers for removal of phosphorus, magnesium, and silica. Cooling tower water is further controlled by addition of dispersants, defoaming agents, and sodium

* 5:5:3:1 refers to constituent limits of 5 mg/l BOD, 5 mg/l TSS, 3 mg/l nitrogen and 1 mg/l phosphorus.

Source: DeStefano, 2000

It is important to note that, in all cases for the facilities contacted, the quality of wastewater treatment at each WWTP is governed by the receiving water body where the treated effluent is discharged, and its classification. For example, if the water body serves as a source of drinking water or is an important fishery, any treated effluent discharged into it would have to be of high quality. Effluent discharged to an urban river or to the ocean could be of lower quality.

2.7.9 Agricultural Reuse in Tallahassee, Florida

The Tallahassee agricultural reuse system is a cooperative operation where the city owns and maintains the irrigation system, while the farming service is under contract to commercial enterprise. During the evolution of the system since 1966, extensive evaluation and operational flexibility have been key factors in its success.

The City of Tallahassee was one of the first cities in Florida to use reclaimed water for agricultural purposes. In 1966, the City began to use reclaimed water from its secondary wastewater treatment plant for spray irrigation. In 1971, detailed studies showed that the system was successful in producing crops for agricultural use. The studies also concluded that the soil was effective at removing SS, BOD, bacteria, and phosphorus from the reclaimed water. Until 1980, the system was limited to irrigation of 120 acres (50 hectares) of land used for hay production. Based upon success of the early studies and experience, a new spray field was constructed in 1980, southeast of Tallahassee.

The southeast spray field has been expanded 3 times since 1980, increasing its total area to approximately 2100 acres (840 hectares). The permitted application rate of the site is 3.16 inches per week (8 cm per week), for a total capacity of 24.5 mgd (1073 l/s). Sandy soils account for the high application rate. The soil composition is about 95 percent sand, with an interspersed clay layer at a depth of approximately 33 feet (10 meters). The spray field has gently rolling topography with surface elevations ranging from 20 to 70 feet (6 to 21 meters) above sea level.

Secondary treatment is provided to the City's Thomas P. Smith wastewater reclamation plant and the Lake Bradford Road wastewater reclamation plant. The reclaimed water produced by these wastewater reclamation plants meet water quality requirements of 20 mg/l for BOD and TSS, and 200/100 ml for fecal coliform. Reclaimed water is pumped approximately 8.5 miles (13.7 km) from the treatment plant to the spray field and distributed via 16 center-pivot irrigation units.

Major crops produced include corn, soybeans, coastal Bermuda grass, and rye. Corn is stored as high-moisture grain prior to sale, and soybeans are sold upon harvest. Both the rye and Bermuda grass are grazed by cattle. Some of the Bermuda grass is harvested as hay and haylage. Cows are allows to graze in winter.

2.7.10 Spray Irrigation at Durbin Creek WWTP Western Carolina Regional Sewer Authority

The Durbin Creek Wastewater Treatment Facility, located near Fountain Inn, South Carolina, is operated by the Western Carolina Regional Sewer Authority (WCRSA). The plant discharges to Durbin Creek, a relatively small tributary of the Enoree River. Average flow from the Durbin Creek Plant is 1.37 mgd (5.2 x 10^3 m^3/day) with a peak flow of 6.0 mgd (22.7 x 10^3 m^3/day) during storm events. The plant is permitted for an average flow of 3.3 mgd (12.5 x 10^3 m^3/day).

The Durbin Creek plant is located on an 200-acre (81-hectare) site. Half of the site is wooded with the remaining half cleared for land application of biosolids. Hay is harvested in the application fields. Much of the land surrounding the plant site is used as a pasture and for hay production without the benefit of biosolids applications.

As a result of increasingly stringent NPDES permit limits and the limited assimilative capacity of the receiving stream, WCRSA began a program to eliminate surface water discharge at this facility. Commencing in 1995, WCRSA undertook a detailed evaluation of land application and reuse at Durbin Creek. The initial evaluation focused on controlling ammonia discharged to the receiving stream by combining agricultural irrigation with a hydrograph-controlled discharge strategy.

In order to appreciate the potential for reuse and land application to address current permit issues facing the Durbin Creek WWTP, a brief discussion of their origin is necessary. South Carolina develops waste load allocations calculated by a model that is based on EPA discharge criteria. Model inputs include stream flow, background concentrations of ammonia, discharge volume, water temperature, pH, and whether or not salmonids are present. Because water temperature is part of the model input, a summer (May through October) and a winter (November through April) season are recognized in the current NPDES permit. Ammonia concentrations associated with both acute and chronic toxicity are part of the model output. The stream flow used in the model is the estimated 7-day, 10-year low flow event (7Q10). For the receiving stream, the 7Q10 value is 2.9 cfs (0.08 m^3/s).

The permitted flow of 3.3 mgd (12.5 x 10^3 m^3/day) is used as the discharge volume in the model.

A detailed evaluation of the characteristics of the receiving water body flow was required to evaluate the potential of reuse to address the proposed NPDES limits. The probability of occurrence of a given 7-day low flow rate was then determined using an appropriate probability distribution. The annual summer and winter 7Q10 flows for the Durbin Creek site were then estimated with the following results:

Annual	7Q10 2.9 cfs (0.08 m^3/s)
Summer	7Q10 (May through October) 2.9 cfs (0.08 m^3/s)
Winter	7Q10 (November through April) 6.4 cfs (0.18 m^3/s)

The predicted annual 7Q10 of 2.9 cfs (0.08 m^3/s) matched the value used by the state regulatory agency and confirmed the validity of the analysis. The winter 7Q10 was found to be more than double that of the summer 7Q10. This information was then used in conjunction with the state's ammonia toxicity model to develop a conceptual summer and winter discharge permit for effluent discharge based on stream flow.

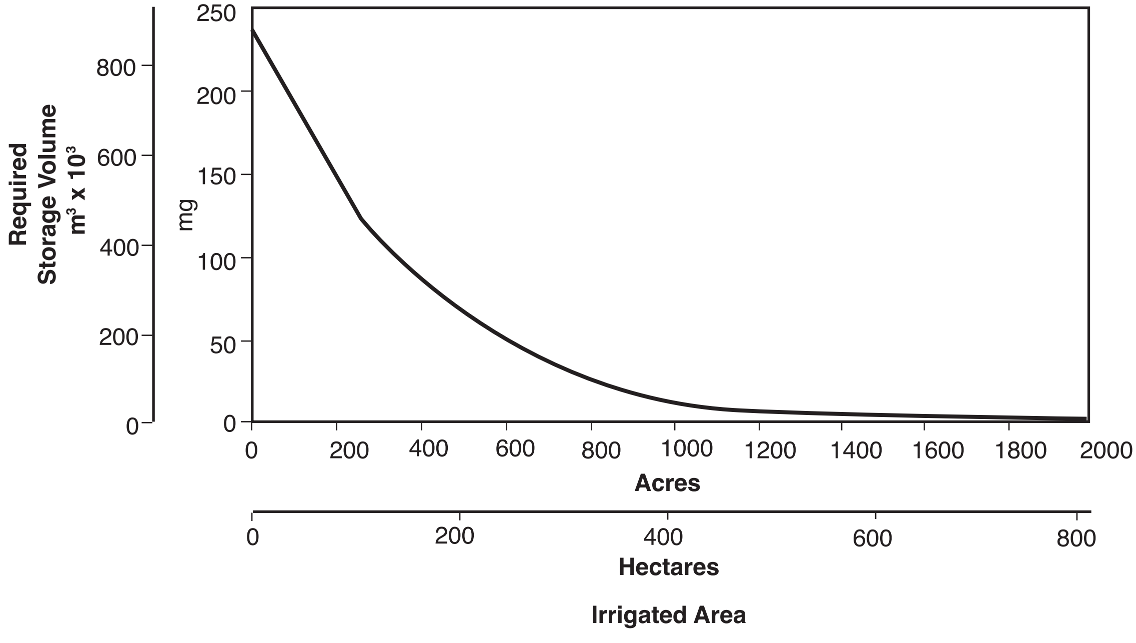
The next step was to evaluate various methods of diverting or withholding a portion of the design discharge flow under certain stream flow conditions.

The most prominent agricultural enterprise in the vicinity of the Durbin Creek WWTP is hay production. Thus, WCRSA decided to investigate agricultural reuse as its first alternative disposal method.

To evaluate how irrigation demands might vary over the summer season, a daily water balance was developed to calculate irrigation demands. The irrigation water balance was intended to calculate the consumptive need of an agricultural crop as opposed to hydraulic capacities of a given site. This provision was made because farmers who would potentially receive reclaimed water in the future would be interested in optimizing hay production and could tolerate excess irrigation as a means of disposal. Results of this irrigation water balance were then combined with the expected stream flow to evaluate the requirements of integrating agricultural irrigation with a hydrograph control strategy.

The results of this analysis are provided in **Figure 2-16,** which indicates the storage volume required as a function of the irrigated area given a design flow of 3.3 mgd (12.5 x 10^3 m^3/day). As shown in Figure 2-16, if no irrigated area is provided, a storage volume of approximately 240 million gallons (900 x 10^3 m^3) would be required to

Figure 2-16. Durbin Creek Storage Requirements as a Function of Irrigated Area



achieve compliance with a streamflow dependent permit. This storage volume decreases dramatically to approximately 50 million gallons (190 x 10^3 m^3) if 500 acres (200 hectares) of irrigated area are developed. As irrigated area increases from 500 to 1,200 acres (200 to 490 hectares), the corresponding ratio of increased irrigated area to reduction in storage is less. As indicated in Figure 2-16, storage could hypothetically be completely eliminated given an irrigated area of approximately 1,900 acres (770 hectares). The mathematical modeling of stream flows and potential demands has demonstrated that reuse is a feasible means of achieving compliance with increasingly stringent NPDES requirements in South Carolina.

2.7.11 Agricultural Irrigation of Vegetable Crops: Monterey, California

Agriculture in Monterey County, located in the central coastal area of California, is a $3 billion per year business. The northern part of the county produces a variety of vegetable crops, many of which may be consumed raw. As far back as the 1940s, residential, commercial, industrial, and agricultural users were overdrawing the County's northern groundwater supply. This overdraw lowered the water tables and created an increasing problem of saltwater intrusion. In the mid-1970s, the California Central Coast Regional Water Quality Control Board completed a water quality management plan for the area, recommending reclaimed water for crop irrigation.

At that time, agricultural irrigation of vegetable crops with reclaimed water was not widely accepted. To respond to questions and concerns from the agricultural community, the Monterey Regional Water Pollution Control Agency (MRWPCA) sponsored an 11-year, $7-million pilot and demonstration project known as the Monterey Wastewater Reclamation Study for Agriculture (MWRSA). Study objectives were to find answers to questions about such issues as virus and bacteria survival on crops, soil permeability, and yield and quality of crops, as well as to provide a demonstration of field operations for farmers who would use reclaimed water.

Five years of field operations were conducted, irrigating crops with 2 types of tertiary treated wastewater, with a well water control for comparison. Artichokes, broccoli, cauliflower, celery, and several varieties of lettuce were grown on test plots and a demonstration field. Crops produced with reclaimed water were healthy and vigorous, and the system operated without complications. The results of the study provided evidence that using reclaimed water can be as safe as irrigating with well water, and that large scale water reclamation can be accomplished. No virus was found in reclaimed water used for irrigation or on samples of crops grown with the reclaimed water. No tendency was found for metals to accumulate in soils or on plant tissues. Soil permeability was not impaired. By the time the study was completed in 1987, the project had gained widespread community support for water reclamation.

As a result of the MWRSA, a water reclamation plant and distribution system were completed in 1997. The project was designed to serve 12,000 acres (4,850 hectares) of artichokes, lettuce, cauliflower, broccoli, celery, and strawberries. Delivery of reclaimed water was delayed until spring of 1998 to address new concerns about emerging pathogens. The reclaimed water was tested for *E. Coli* 0157:H7, *Legionella*, *Salmonella*, *Giardia*, *Cryptosporidium*, and *Cyclospora*. No viable organisms were found and the results were published in the *Recycled Water Food Safety Study*. This study increased grower and buyer confidence. Currently, 95 percent of the project acreage is voluntarily using reclaimed water.

Growers felt strongly that health department regulations should be minimal regarding use of reclaimed water. The MRWPCA succeeded in getting the County Health Department to approve wording requirements for signs along public roads through the project to say, "No Trespassing," rather than previously proposed wording that was detrimental to public acceptance of reclaimed water. Similarly, field worker safety training requires only that workers not drink the water, and that they wash their hands before eating or smoking after working with reclaimed water.

Three concerns remain: safety, water quality, and long term soil health. To address safety, pathogen testing continues and results are routinely placed on the MRWPCA website at www.mrwpca.org. The water quality concern is partly due to chloride, but mostly due to sodium concentration levels. MRWPCA works with sewer users to voluntarily reduce salt levels by using more efficient water softeners, and by changing from sodium chloride to potassium chloride for softener regeneration. In 1999, the agency began a program of sampling soils from 3 different depth ranges 3 times each season from 4 control sites (using well water) and 9 test sites (using reclaimed water). Preliminary results indicate that using reclaimed water for vegetable production is not causing the soil to become saline.

2.7.12 Water Conserv II: City of Orlando and Orange County, Florida

As a result of a court decision in 1979, the City of Orlando and Orange County, Florida, were mandated to cease discharge of their effluent into Shingle Creek, which flows into Lake Tohopekaliga, by March 1988. The City and County immediately joined forces to find the best and most cost-effective solution. Following several rounds of extensive research, the decision was made to construct a reuse project in West Orange and Southeast Lake counties along a high, dry, and sandy area known as the Lake Wales Ridge. The project was named Water Conserv II. The primary use of the reclaimed water would be for agricultural irrigation. Daily flows not needed for irrigation would be distributed into rapid infiltration basins (RIBs) for recharge of the Floridan aquifer.

Water Conserv II is the largest reuse project of its type in the world, a combination of agricultural irrigation and RIBs. It is also the first reuse project in Florida permitted by the Florida Department of Environmental Protection to irrigate crops produced for human consumption with reclaimed water. The project is best described as "a cooperative reuse project by the City of Orlando, Orange County, and the agricultural community." The City and County jointly own Water Conserv II.

The project is designed for average flows of 50 mgd (2,190 l/s) and can handle peak flows of 75 mgd (3,285 l/s). Approximately 60 percent of the daily flows are used for irrigation, and the remaining ±40 percent is discharged to the RIBs for recharge of the Floridan aquifer. Water Conserv II began operation on December 1, 1986.

At first, citrus growers were reluctant to sign up for reclaimed water. They were afraid of potential damage to their crops and land from the use of the reclaimed water. The City and County hired Dr. Robert C.J. Koo, a citrus irrigation expert at the University of Florida's Citrus Research Center at Lake Alfred, to study the use of reclaimed water as an irrigation source for citrus. Dr. Koo concluded that reclaimed water would be an excellent source of irrigation water for citrus. The growers were satisfied and comfortable with Dr. Koo's findings, but wanted long-term research done to ensure that there would be no detrimental effects to the crop or land from the long-term use of reclaimed water. The City and County agreed, and the Mid Florida Citrus Foundation (MFCF) was created.

The MFCF is a non-profit organization conducting research on citrus and deciduous fruit and nut crops. All research is conducted by faculty from the University of Florida's Institute of Food and Agricultural Sciences (IFAS). The MFCF Board of Directors is comprised of citrus growers in north central Florida and representatives from the City of Orlando, Orange County, the University of Florida IFAS, and various support industries. Goals of the MFCF are to develop management practices that will allow growers in the northern citrus area to re-establish citrus and grow it profitably, provide a safe and clean environment, find solutions to challenges facing citrus growers, and promote urban and rural cooperation. All research conducted by the MFCF is located within the Water Conserv II service area. Reclaimed water is used on 163 of the 168 acres of research. MFCF research work began in 1987.

Research results to date have been positive. The benefits of irrigating with reclaimed water have been consistently demonstrated through research since 1987. Citrus on ridge (sandy, well drained) soils respond well to irrigation with reclaimed water. No significant problems have resulted from the use of reclaimed water. Tree condition and size, crop size, and soil and leaf mineral aspects of citrus trees irrigated with reclaimed water are typically as good as, if not better than, groves irrigated with well water. Fruit quality from groves irrigated with reclaimed water was similar to groves irrigated with well water. The levels of boron and phosphorous required in the soil for good citrus production are present in adequate amounts in reclaimed water. Thus, boron and phosphorous can be eliminated from the fertilizer program. Reclaimed water maintains soil pH within the recommended range; therefore, lime no longer needs to be applied.

Citrus growers participating in Water Conserv II benefit from using reclaimed water. Citrus produced for fresh fruit or processing can be irrigated by using a direct contact method. Growers are provided reclaimed water 24 hours per day, 7 days per week at pressures suitable for micro-sprinkler or impact sprinkler irrigation. At present, local water management districts have issued no restrictions for the use of reclaimed water for irrigation of citrus. By providing reclaimed water at pressures suitable for irrigation, costs for the installation, operation, and maintenance of a pumping system can be eliminated. This means a savings of $128.50 per acre per year ($317 per hectare per year). Citrus growers have also realized increased crop yields of 10 to 30 percent and increased tree growth of up to 400 percent. The increases are not due to the reclaimed water itself, but the availability of the water in the soil for the tree to absorb. Growers are maintaining higher soil moisture levels.

Citrus growers also benefit from enhanced freeze protection capabilities. The project is able to supply enough water to each grower to protect his or her entire production area. Freeze flows are more than 8 times higher than normal daily flows. It is very costly to the City and County to provide these flows (operating costs average $15,000 to $20,000 per night of operation), but they feel it is well worth the cost. If growers were to be frozen out, the project would lose its customer base. Sources of water to meet freeze flow demands include normal daily flows of 30 to 35 mgd (1,310 to 1,530 l/s), 38 million gallons of stored water (143,850 m^3), 80 mgd (3,500 l/s) from twenty-five 16-inch diameter wells, and, if needed, 20 mgd (880 l/s) of potable water from the Orlando Utilities Commission.

Water Conserv II is a success story. University of Florida researchers and extension personnel are delighted with research results to date. Citrus growers sing the praises of reclaimed water irrigation. The Floridan aquifer is being protected and recharged. Area residents view the project as a friendly neighbor and protector of the rural country atmosphere.

2.7.13 The Creation of a Wetlands Park: Petaluma, California

The City of Petaluma, California, has embarked on a project to construct a new water reclamation facility. The existing wastewater plant was originally built in 1938, and then upgraded over the years to include oxidation ponds for storage during non-discharge periods. The city currently uses pond effluent to irrigate 800 acres (320 hectares) of agricultural lands and a golf course. As part of the new facility, wetlands are being constructed for multiple purposes including treatment (to reduce suspended solids, metals, and organics), reuse, wildlife habitat, and public education and recreation. The citizens of Petaluma have expressed a strong interest in creating a facility that not only provides wastewater treatment and reuse, but also serves as a community asset. In an effort to further this endeavor, the citizens formed an organization called the Petaluma Wetlands Park Alliance.

Currently, the project is being designed to include 30 acres (12 hectares) of vegetated wetlands to remove algae. The wetlands will be located downstream from the City's oxidation ponds. The vegetated treatment wetlands will not be accessible to the general public for security reasons. However, an additional 30 acres (12 hectares) of polishing wetlands with both open water and dense vegetation zones will be constructed on an adjacent parcel of land. These polishing wetlands will be fed by disinfected water from the treatment wetlands, so public access will be allowed. Berms around all 3 wetland cells will provide access trails.

The parcel of land where the polishing wetlands will be constructed has many interesting and unique features. An existing creek and riparian zone extend through the upland portion of the parcel down to the Petaluma River. The parcel was historically farmed all the way to the river, but in an El Nino event, the river levees breached and 132 acres (53 hectares) of land has been returned to tidal mudflat/marsh. The parcel is directly adjacent to a city park, with trails surrounding ponds for dredge spoils. A plan has been developed to connect the 2 parcels via trails for viewing the tidal marsh, the polishing wetlands, and the riparian/creek area. The plan also calls for restoration and expansion of the riparian zone, planting of native vegetation, and restoration/enhancement of the tidal marsh. The polishing wetlands will be constructed on a portion of the 133 acres (54 hectares) of uplands. The remainder of the upland areas will either be restored for habitat or cultivated as a standing crop for butterfly and bird foraging. Landscaping on the wetlands site will be irrigated with reclaimed water. A renowned environmental artist developed the conceptual plan with an image of the dog-faced butterfly formed by the wetland cells and trails.

Funding for acquisition of the land and construction of the trails and restoration projects has been secured from the local (Sonoma County) open space district and the California Coastal Conservancy in the amount of $4 million. The citizen's alliance has continued to promote the concept. The alliance recently hosted a tour of the site with the National Audubon Society, asking that the site be considered for the location of an Audubon Interpretive Center.

2.7.14 Geysers Recharge Project: Santa Rosa, California

The cities of central Sonoma County, California, have been growing rapidly, while at the same time regulations governing water reuse and discharge have become more stringent. This has taxed traditional means of reusing water generated at the Laguna Wastewater Plant and Reclamation Facility. Since the early 1960s, the Santa Rosa Subregional Water Reclamation System has provided reclaimed water for agricultural irrigation in the Santa Rosa Plain, primarily to forage crops for dairy farms. In the early 1990s, urban irrigation uses were added at Sonoma State University, golf courses, and local parks. The remaining reclaimed water not used for irrigation was discharged to the Laguna de Santa Rosa from October through May. But limited storage capacity, conversion of dairy farms to vineyards (decreasing reclaimed water use by over two-thirds), and growing concerns over water quality impacts in the Laguna de Santa Rosa, pressured the system to search for a new and reliable means of reuse.

In the northwest quadrant of Sonoma County lies the Geysers Geothermal Steamfield, a super-heated steam resource used to generate electricity since the mid 1960s. At its peak in 1987, the field produced almost 2,000 megawatts (MW), enough electricity to supply an estimated 2 million homes and businesses with power. Geysers operators have mined the underground steam to such a degree over the years that electricity production has declined to about 1,200 MW. As a result, the operators are seeking a source of water to recharge the deep aquifers that yield steam. Geothermal energy is priced competitively with fossil fuel and hydroelectric sources, and is an important “green” source of electricity. In 1997, a neighboring sewage treatment district in Lake County successfully implemented a project to send 8 mgd (350 l/s) of secondary-treated water augmented with Clear Lake water to the southeast Geysers steamfields for recharge. In 1998, the Santa Rosa Subregional Reclamation System decided to build a conveyance system to send 11 mgd (480 l/s) of tertiary-treated water to the northwest Geysers steamfield for recharge. The Santa Rosa contribution to the steamfield is expected to yield an additional 85 MW or more of electricity production.

The conveyance system to deliver water to the steamfield includes 40 miles (64 km) of pipeline, 4 large pump stations, and a storage tank. The system requires a lift of 3,300 feet (1,005 meters). Distribution facilities within the steamfield include another 18 miles (29 km) of pipeline, a pump station, and tank, plus conversion of geothermal wells from production wells to injection wells.

The contract with the primary steamfield operator, Calpine Corporation, states that Calpine is responsible for the construction and operation of the steamfield distribution system and must provide the power to pump the water to the steamfield. The Subregional Reclamation System, in turn, is responsible for the construction and operation of the conveyance system to the steamfield and provides the reclaimed water at no charge. The term of the contract is for 20 years with an option for either party to extend for another 10 years.

One of the major benefits of the Geysers Recharge Project is the flexibility afforded by year-round reuse of water. The system has been severely limited because of seasonal discharge constraints and the fact that agricultural reuse is not feasible during the wet winter months. The Geysers steamfield will use reclaimed water in the winter, when no other reuse options are available. However, during summer months, demand for reuse water for irrigation is high. The system will continue to serve agricultural and urban users while maintaining a steady but reduced flow of reclaimed water to the Geysers. A detailed daily water balance model was constructed to assist in the design of the initial system and to manage the optimum blend of agricultural, urban, and Geysers recharge uses.

In addition to the benefits of power generation, the Geysers Recharge Project will bring an opportunity for agricultural reuse along the Geysers pipeline alignment, which traverses much of Sonoma County’s grape-growing regions. Recent listings of coho salmon and steelhead trout as threatened species may mean that existing agricultural diversions of surface waters will have to be curtailed. The Geysers pipeline could provide another source of water to replace surface water sources, thereby preserving the habitat of the threatened species.

2.7.15 Advanced Wastewater Reclamation in California

The Groundwater Replenishment (GWR) System is a regional water supply project sponsored jointly by the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD) in southern California. Planning between OCWD and OCSD eventually led to the decision to replace Water Factory 21 (WF21) with the GWR System. OCSD, an early partner with OCWD in WF21, will continue to supply secondary wastewater to the GWR System. As one of the largest advanced reclaimed water facilities in the world, the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County groundwater basin. For OCSD, reusing the water will also provide peak wastewater flow disposal relief and postpone the need to construct a new ocean outfall by diverting treated wastewater flows that would otherwise be discharged to the Pacific Ocean.

The GWR System addresses both water supply and wastewater management needs through beneficial reuse of highly treated wastewater. OCWD is the local agency responsible for managing and protecting the lower Santa Ana River groundwater basin. Water supply needs include both the quantity and quality of water. The GWR System offers a new source of water to meet future increasing demands from the region’s groundwater producers, provides a reliable water supply in times of drought, and reduces the area’s dependence on imported water. The GWR System will take treated secondary wastewater from OCSD (activated sludge and trickling filter effluent) and purify it using microfiltration (MF), reverse osmosis (RO) and ultraviolet (UV) disinfection. Lime is added to stabilize the water. This low-salinity water (less than 100 mg/l TDS) will be injected into the seawater barrier or percolated through the ground into Orange County’s aquifers, where it will blend with groundwater from other sources, including imported and Santa Ana River stormwater, to improve the water quality. The GWR System will produce a peak daily production capacity of 78,400 acre-feet per year (70 mgd or 26,500 m^3/yr) in the initial phase and will ultimately produce nearly 145,600 acre-feet per year (130 mgd or 492,100 m^3/yr) of a new, reliable, safe drinking water supply, enough to serve over 200,000 families. Over time, the water produced by the GWR System will lower the salinity of groundwater by replacing the high-TDS water currently percolated into the groundwater basin with low-TDS reclaimed water from the GWR System. The project conforms to the California State Constitution by acknowledging the value of reclaimed water. Less energy is used to produce the GWR System water than would be required to import an equivalent volume of water, reducing overall electrical power demand in the region.

The GWR System will also expand the existing seawater intrusion barrier to protect the Orange County groundwater basin from further degradation. The groundwater levels have been lowered significantly in some areas of the groundwater basin due to the substantial coastal pumping required to meet peak summer potable water demands. The objective of the barrier is to create a continuous mound of freshwater that is higher than sea level, so that the seawater cannot migrate into the aquifer. As groundwater pumping activities increase, so do the amounts of freshwater required to maintain the protective mound. OCWD currently operates 26 injection wells to supply water to the barrier first created in the mid 1970s. Additional water is required to maintain a suitable barrier. To determine optimal injection well capacities and locations, a Talbert Gap groundwater computer model was constructed and calibrated for use as a predictive tool. Based on the modeling analysis, 4 new barrier wells will be constructed in an alignment along the Santa Ana River to cut off saltwater intrusion at the east end of the Talbert Gap. The modeling results also indicate that a western extension of the existing barrier is required. Twelve new barrier wells will be constructed at the western end of the Talbert Gap to inhibit saltwater intrusion under the Huntington Beach mesa.

The project benefits OCSD's wastewater management effort as well as helping to meet Orange County's water supply requirements. The GWR System conforms to the OCSD Charter, which supports water reuse as a scarce natural resource. By diverting peak wastewater effluent discharges, the need to construct a new ocean outfall is deferred, saving OCSD over $175 million in potential construction costs. These savings will be used to help off-set the cost of the GWR system where OCSD will pay for half of the Phase 1 construction. The GWR System also reduces the frequency of emergency discharges near the shore, which are a significant environmental issue with the local beach communities.

2.7.16 An Investigation of Soil Aquifer Treatment for Sustainable Water

An intensive study, entitled, "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse," was conducted to assess the sustainability of several different SAT systems with different site characteristics and effluent pretreatments (AWWARF, 2001). The sites selected for study and key characteristics of the sites are presented in **Table 2-15**.

Main objectives of the study were to: (1) examine the sustainability of SAT systems leading to indirect potable reuse of reclaimed water; (2) characterize the processes that contribute to removal of organics, nitrogen, and viruses during transport through the infiltration interface, soil percolation zone, and underlying groundwater aquifer; and (3) develop relationships among above-ground treatment and SAT for use by regulators and utilities.

The study reported the following results:

- Dissolved organic carbon (DOC) present in SAT product water was composed of natural organic matter (NOM), soluble microbial products that resemble NOM, and trace organics.
- Characterization of the DOC in SAT product water determined that the majority of organics present were not of anthropenic origin.
- The frequency of pathogen detection in SAT products waters could not be distinguished from the frequency of pathogen detection in other groundwaters.
- Nitrogen removal during SAT was sustained by anaerobic ammonia oxidation.

The study reported the following impacts:

- Effluent pretreatment did not affect final SAT product water with respect to organic carbon concentrations. A watershed approach may be used to predict SAT product water quality.
- Removal of organics occurred under saturated anoxic conditions and a vadose zone was not necessary for an SAT system. If nitrogen removal is desired during SAT, nitrogen must be applied in a reduced form, and a vadose zone combined with soils that can exchange ammonium ions is required.

Table 2-15. Field Sites for Wetlands/SAT Research

Facility	Key Site Characteristics
Sweetwater Wetlands/Recharge Facility, AZ	Deep vadose zone (>100 feet) with extensive vadose zone monitoring capabilities and several shallow groundwater wells located downgradient.
Mesa Northwest, AZ	Shallow vadose zone (5-20 feet). Multi-depth sampling capabilities below basins. Array of shallow groundwater wells located from 500 feet to greater than 10,000 feet from recharge site.
Phoenix Tres Rios Cobble Site, AZ	Horizontal flow and shallow (<21 feet) saturated zone sampling capabilities. Majority of flow infiltrates into groundwater.
Rio Hondo/Montebello Forebay, CA	Vadose zone (20-50 feet). Water supply is a mixture of reclaimed water and other available water sources. Multi-depth sampling capabilities.
San Gabriel/Montebello Forebay, CA	Shallow vadose zone (10-20 feet). Water supply is a mixture of reclaimed water and other available water sources. Multi-depth sampling capabilities.
Riverside Water Quality Control Plant Hidden Valley Wetlands, CA	Horizontal flow and shallow (<3 feet) vadose zone sampling capabilities. Approximately 25% of flow infiltrates into groundwater.
East Valley (Hansen Spreading Grounds), CA	Deep vadose zone (>100 feet). Multi-depth and downgradient sampling capabilities exist.
Avra Valley Wastewater Treatment Facility, AZ	Wastewater treatment applied is similar to facilities in Mesa and Phoenix, Arizona. However, drinking water supply is based only on local groundwater.

- The distribution of disinfection by-products produced during chlorination of SAT product water was affected by elevated bromide concentrations in reclaimed water.

2.7.17 The City of West Palm Beach, Florida Wetlands-Based Water Reclamation Project

The City of West Palm Beach water supply system consists of a 20-square-mile (52-km^2) water catchment area and surface water allocation from Lake Okeechobee, which flows to a canal network that eventually terminates at Clear Lake, where the City's water treatment plant is located. As part of the Everglades restoration program, the timing, location, and quantity of water releases to the South Florida Water Management District (SFWMD) canals from Lake Okechobee will be modified. More water will be directed towards the Everglades for hydropattern restoration and less water will be sent to the SFWMD canals. This translates into less water available for water supplies in the lower east coast area. Therefore, indirect potable reuse, reuse for aquifer recharge purposes, and aquifer storage and recovery are some of the alternative water supply strategies planned by the City of West Palm Beach.

The City of West Palm Beach has developed a program to use highly treated wastewater from their East Central Regional Wastewater Treatment Plant (ECRWWTP) for beneficial reuse including augmentation of their drinking water supply. Presently, all of the wastewater effluent from the ECRWWTP (approximately 35 mgd [1,530 l/s] average daily flow) is injected over 3,000 feet (914 meters) into the groundwater (boulder zone) using 6 deep wells. Rather than continuing to dispose of the wastewater effluent, the City of West Palm Beach developed the Wetlands-Based Water Reclamation Project (WBWRP). The project flow path is shown in **Figure 2-17**.

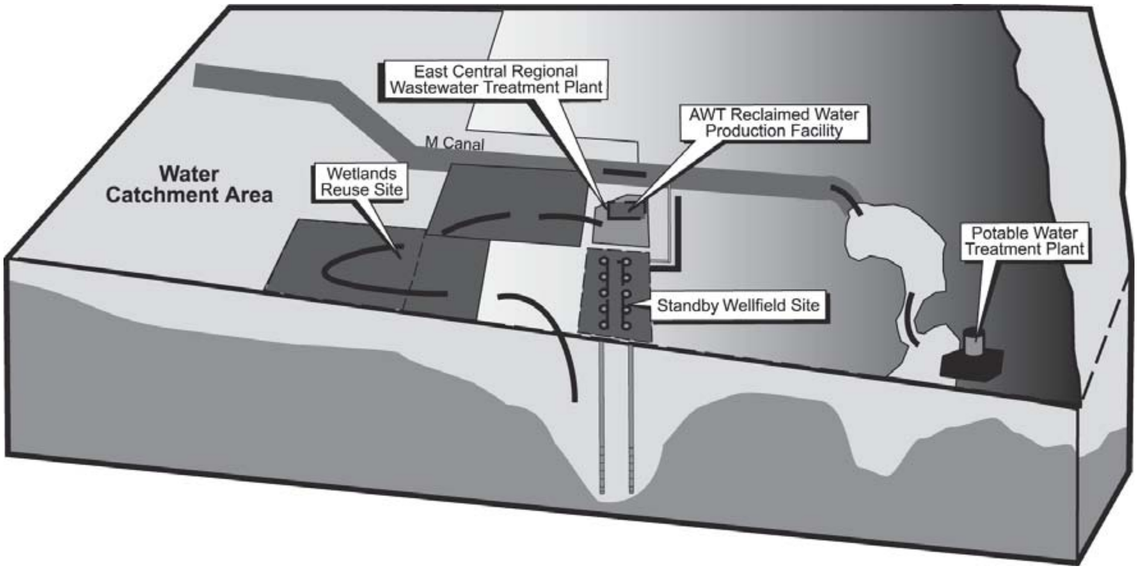
To protect and preserve its surface water supply system and to develop this reuse system to augment the water supply, the City purchased a 1,500-acre (607-hectare) wetland reuse site. This site consists of a combination of wetlands and uplands. A portion of this property was used for the construction of a standby wellfield. The standby wellfield site covers an area of 323 acres (131 hectares) and consists of wetlands and uplands dominated by Melaleuca trees. Two important goals of the project were to: (1) develop an advanced wastewater treatment facility at the ECRWWTP that could produce reclaimed water that, when discharged, would be compatible with the hydrology and water quality at the wetland reuse site, and (2) produce a reliable water supply to augment the City's surface water supply. Treatment was to be provided by the reclaimed water production facility, wetlands, and through aquifer recharge. Groundwater withdrawal would meet drinking water and public health standards. Monitoring was performed at the wetland reuse site from July 1996 to August 1997. The purpose of this monitoring was to establish baseline conditions in the wetlands prior to reclaimed water application and to determine the appropriate quality of the reclaimed water that will be applied to the wetland reuse site. In addition to the monitoring of background hydrology, groundwater quality, and surface water quality, the baseline-monitoring program investigated sediment quality, vegetation, fish, and the presence of listed threatened and endangered plant and animal species. Groundwater samples from the wetland reuse site and the standby wellfield met the requirements for drinking water except for iron. Iron was detected in excess of the secondary drinking water standards of 0.3 mg/l at all of the wells, but not in excess of the Class III surface water quality criteria of 1.0 mg/l. Total nitrogen (TN) concentrations in the wetlands ranged from 0.67 mg/l to 3.85 mg/l with an average value of 1.36 mg/l. The concentration of total phosphorus (TP) was low throughout the wetlands, ranging from less than 0.01 to 0.13 mg/l, with an average value of 0.027 mg/l.

In 1995, the City of West Palm Beach constructed a 150,000-gpd (6.6-l/s) AWT constructed wetlands demonstration project. The goals of this project were to demonstrate that an AWT facility could produce an effluent quality of total suspended solids (TSS), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), TN, and TP goals of 5, 5, 3, and 1 mg/l, respectively, and that wetlands could provide some additional treatment prior to discharge. The demonstration facility met the AWT goals as well as all of the surface water quality standards, state and federal drinking water standards (except for iron), and all public health standards (absence of *Cryptosporidium*, *Giardia*, enteric viruses, and coliforms).

A hydrologic model capable of simulating both groundwater flow and overland flow was constructed and calibrated to assess the hydrology, hydrogeology, and potential hydraulic conveyance characteristics within the project area. The model indicated that maintenance of viable wetlands (i.e., no extended wet or dry periods) can be achieved at the wetland reuse site, the standby wellfield, and with aquifer recharge to augment the water supply.

Reclaimed water will initially be applied to the wetland reuse site at a rate of 2 inches (5 cm) per week, which corresponds to a reclaimed water flow of approximately 6 mgd (263 l/s) over 770 acres (312 hectares) of the 1,415-acre (573-hectare) site. The results of the modeling indicate that up to 6 mgd (263 l/s) of reclaimed water can be applied to the wetland reuse site without producing more than an 8-inch (20-cm) average rise in surface water levels in the wetlands. A particle tracking analysis was conducted to evaluate the fate of discharge at the wetland reuse site and the associated time of travel in the surficial aquifer. The particle tracking analysis indicated that the travel time from the point of reclaimed

Figure 2-17. Project Flow Path



water application to the point of groundwater discharge (from the standby wellfield to the M Canal) ranged from 2 to 34 years. The M Canal flows into the City's surface water reservoir.

Based on the results of the demonstration project, a 10-mgd (438-l/s) reclaimed water facility was designed with operational goals for TN and TP of less than 2.0 mg/l and 0.05 mg/l (on an annual average basis) respectively, in order to minimize change in the wetland vegetation. A commitment to construction and operation of a high-quality reclaimed water facility has been provided to meet these stringent discharge requirements.

Public participation for this project consisted of holding several tours and meetings with regulatory agencies, public health officials, environmental groups, media, and local residents from the early planning phases through project design. Brochures describing the project drivers, proposed processes, safety measures, and benefits to the community were identified. A public relations firm was also hired to help promote the project to elected officials and state and federal policy makers.

2.7.18 Types of Reuse Applications in Florida

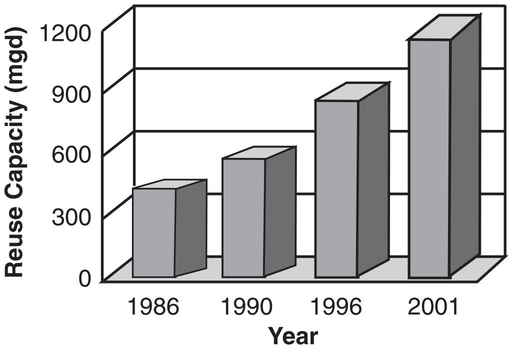
Florida receives an average of more than 50 inches (127 cm) of rainfall each year. While the state may appear to have an abundance of water, continuing population growth, primarily in the coastal areas, contributes to increased concerns about water availability. The result is increased emphasis on water conservation and reuse as a means to more effectively manage state water resources (FDEP, 2002a).

By state statute, Florida established the encouragement and promotion of water reuse as formal state objectives (York *et al*., 2002). In response, the Florida Department of Environmental Protection (FDEP), along with the state's water management districts and other state agencies, have implemented comprehensive programs designed to achieve these objectives.

As shown in **Figure 2-18**, the growth of reuse in Florida during 1986 to 2001 has been remarkable (FDEP, 2002b). In 2001, reuse capacity totaled 1,151 mgd (50,400 l/s), which represented about 52 percent of the total permitted capacity of all domestic wastewater treatment facilities in the state. About 584 mgd (25,580 l/s) of reclaimed water were used for beneficial purposes in 2001.

The centerpiece of Florida's Water Reuse Program is a detailed set of rules governing water reuse. Chapter 62-610, Florida Administrative Code (Florida DEP, 1999), includes discussion of landscape irrigation, agricultural irrigation, industrial uses, groundwater recharge, indirect potable reuse, and a wide range of urban reuse activities. This rule also addresses reclaimed water ASR, blending of demineralization concentrate with reclaimed water, and the use of supplemental water supplies.

Figure 2-18. Growth of Reuse in Florida



Source: Florida DEP, 2002b

Given the complexity of the program and the number of entities involved, program coordination is critical. The Reuse Coordinating Committee, which consists of representatives of the Florida DEP, Florida's 5 water management districts, Florida Department of Health, the Public Service Commission, Florida Department of Agriculture and Consumer Services and Florida Department of Community Affairs, meets regularly to discuss reuse activities and issues. In addition, permitting staffs from the water management districts and the Florida DEP meet regularly to discuss local reuse issues and to bring potential reclaimed water users and suppliers together. Indeed, statutory and rule provisions mandate the use of reclaimed water and implementation of reuse programs (York *et al*., 2002).

Florida's Water Reuse Program incorporates a number of innovations and advancements. Of note is the "*Statement of Support for Water Reuse*", which was signed by the heads of the agencies comprising the Reuse Coordinating Committee. EPA Region 4 also participated as a signatory party. The participating agencies committed to encouraging, promoting, and facilitating water reuse in Florida.

In addition, working as a partner with the Water Reuse Committee of the Florida Water Environment Association, Florida DEP developed the "*Code of Good Practices for Water Reuse*." This is a summary of key management, operation, and public involvement concepts that define quality reuse programs.

As outlined in the Water Conservation Initiative (FDEP, 2002a), the future of Florida's Water Reuse Program will be guided by the need to ensure that reclaimed water is used efficiently and effectively in Florida (York *et al*., 2002). The Water Conservation Initiative report contains 15 strategies for encouraging efficiency and effectiveness in the Water Reuse Program.

2.7.19 Regionalizing Reclaimed Water in the Tampa Bay Area

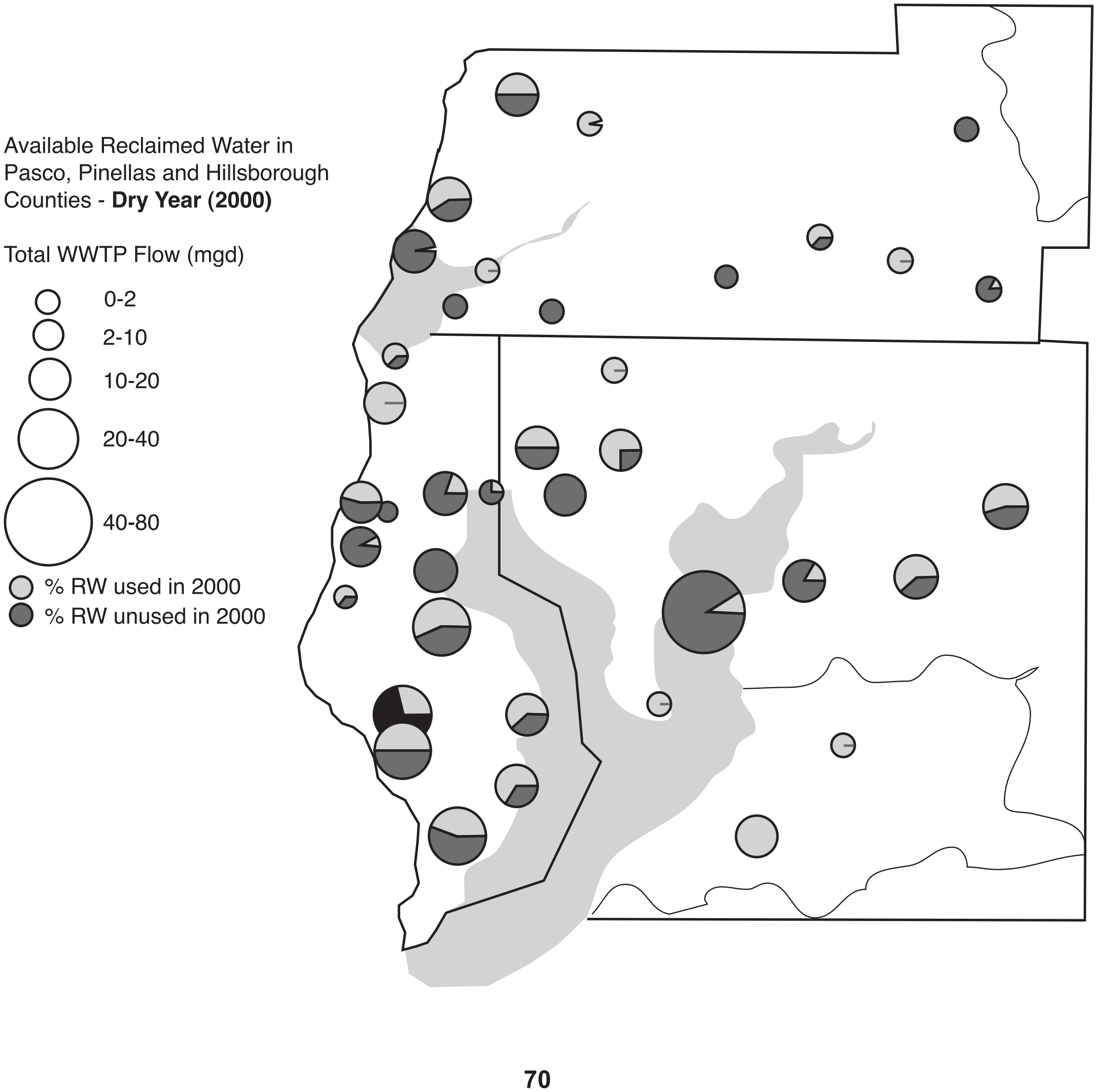
The Southwest Florida Water Management District (SWFMWD) is one of 5 water management districts in the state responsible for permitting groundwater and surface water withdrawals. The Tampa Bay area is within the SWFWMD and has experienced prolonged growth that has strained potable water supplies. A profile of the Tampa Bay area is given below:

- Home to nearly 2.5 million people who live in the 3 counties (Pasco, Hillsborough, and Pinellas) referred to as the Tampa Bay area.

- The largest water user group in the Tampa Bay area is the public, using 306.2 million mgd (13,410 l/s), representing 64 percent of the water total use in the area in the year 2000. There are 38 wastewater treatment facilities in the Tampa Bay area operated by 19 public and private utilities. In 2000 these facilities:

Figure 2-19. Available Reclaimed Water in Pasco, Pinellas, and Hillsborough Counties

Southwest Florida Water Management District



- Produced an annual average of 201 mgd (8,800 l/s) of treated wastewater.

- 73 mgd (3,200 l/s) of reclaimed water was used for beneficial purposes, representing 36 percent use of available flows.

- Of the 73 mgd (3,200 l/s), 44 mgd (1,930 l/s) (60 percent) of reclaimed water replaced the use of traditional, high-quality (potable) water resources.

As the regulatory authority responsible for managing water supplies in the region, SWFWMD views the offset achieved through use of reclaimed water as an important contribution to the regional water supply. The District's "*Regional Water Supply Plan"* includes a goal to effectively use 75 percent of available reclaimed water resources in order to offset existing or new uses of high quality water sources. The objectives to meet the goal by 2020 or earlier are collectively designed to enhance the use and efficiency of reclaimed water by:

- Maximizing reclaimed water locally to meet water demands in service areas
- Increasing the efficiency of use through technology for dealing with wet-weather flows and demand management (i.e., meters, education, etc.)
- Interconnecting systems to move excess flows to areas where the water is needed, when it is needed, for a regional water resource benefit

There is not enough reclaimed water in the Tampa Bay area to meet all of the irrigation and other needs in the region. However, there are opportunities to transport excess reclaimed water flows that cannot be used locally to achieve benefits to areas of high demand or other beneficial uses, such as natural system restoration. As a first step in evaluating how reclaimed water may be used in the Tampa Bay Area, the SWFWMD developed an inventory of existing water reclamation facilities, their locations, total flow and flows already committed to beneficial reuse, and flows that might be available for an expanded reuse program (**Figure 2-19**). Subsequent planning efforts will build on this information to evaluate interconnections between reuse systems for optimal use.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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CHAPTER 3

Technical Issues In Planning Water Reuse Systems

This chapter considers technical issues associated with planning the beneficial reuse of reclaimed water derived from domestic wastewater facilities. These technical issues include the:

- Identification and characterization of potential demands for reclaimed water
- Identification and characterization of existing sources of reclaimed water to determine their potential for reuse
- Treatment requirements for producing a safe and reliable reclaimed water that is suitable for its intended applications
- Storage facilities required to balance seasonal fluctuations in supply with fluctuations in demand
- Supplemental facilities required to operate a water reuse system, such as conveyance and distribution networks, operational storage facilities, alternative supplies, and alternative disposal facilities
- Potential environmental impacts of implementing water reclamation
- Identification of knowledge, skills, and abilities necessary to operate and maintain the proposed system

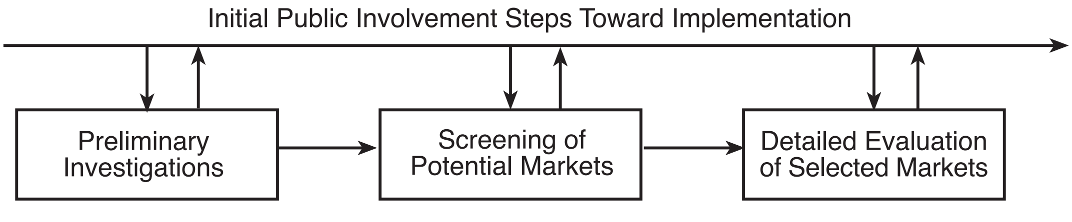
Technical issues of concern in specific reuse applications are discussed in Chapter 2, "Types of Reuse Applications."

3.1 Planning Approach

One goal of the *Guidelines for Water Reuse* is to outline a systematic approach to planning for reuse so that planners can make sound preliminary judgments about the local feasibility of reuse, taking into account the full range of key issues that must be addressed in implementing reclamation programs.

Figure 3-1 illustrates a 3-phase approach to reuse planning. This approach groups reuse planning activities into successive stages that include preliminary investigations, screening of potential markets, and detailed evaluation of selected markets. Each stage of activity builds on previous stages until enough information is available to develop a conceptual reuse plan and to begin negotiating the details of reuse with selected users. At each stage, from early planning through implementation, public involvement efforts play an important role. Public involvement efforts provide guidance to the planning process and outline steps that must be taken to support project implementation.

Figure 3-1. Phases of Reuse Program Planning



3.1.1 Preliminary Investigations

This is a fact-finding phase, meant to rough out physical, economic, and legal/institutional issues related to water reuse planning. The primary task is to locate all potential sources of effluent for reclamation and reuse and all potential markets for reclaimed water. It is also important to identify institutional constraints and enabling powers that might affect reuse. This phase should be approached with a broad view. Exploration of all possible options at this early planning stage will establish a practical context for the plan and also help to avoid creating dead-ends in the planning process.

Questions to be addressed in this phase include:

- What local sources of effluent might be suitable for reuse?
- What are the potential local markets for reclaimed water?
- What other nontraditional freshwater supplies are available for reuse?
- What are the present and projected reliability benefits of fresh water in the area?
- What are the present and projected user costs of fresh water in the area?
- What sources of funding might be available to support the reuse program?
- How would water reuse "integrate," or work in harmony with present uses of other water resources in the area?
- What public health considerations are associated with reuse, and how can these considerations be addressed?
- What are the potential environmental impacts of water reuse?
- What type of reuse system is likely to attract the public's interest and support?
- What existing or proposed laws and regulations affect reuse possibilities in the area?
- What local, state, or federal agencies must review and approve implementation of a reuse program?
- What are the legal liabilities of a purveyor or user of reclaimed water?

The major task of this phase involves conducting a preliminary market assessment to identify potential reclaimed water users. This calls for defining the water market through discussions with water wholesalers and retailers, and by identifying major water users in the market. The most common tools used to gather this type of information are telephone contacts and/or letters to potential reuse customers. Often, a follow-up phone contact is needed in order to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements.

This early planning stage is an ideal time to begin to develop or reinforce strong working relationships, among wastewater managers, water supply agencies, and potential reclaimed water users. These working relationships will help to develop solutions that best meet a particular community's needs.

Potential users will be concerned with the quality of reclaimed water and reliability of its delivery. They will also want to understand state and local regulations that apply to the use of reclaimed water. Potential customers will also want to know about constraints to using reclaimed water. They may have questions about connection costs or additional wastewater treatment costs that might affect their ability to use the product.

3.1.2 Screening of Potential Markets

The essence of this phase is to compare the unit costs of fresh water to a given market and the unit costs of reclaimed water to that same market. On the basis of information gathered in preliminary investigations, one or more "intuitive projects" may be developed that are clear possibilities, or that just "seem to make sense." For example, if a large water demand industry is located next to a wastewater treatment plant, there is a strong potential for reuse. The industry has a high demand for water, and costs to convey reclaimed water would be low. Typically, the cost-effectiveness of providing reclaimed water to a given customer is a function of the customer's potential demand versus the distance of the customer from the source of reclaimed water. In considering this approach, it should be noted that a concentration of smaller customers might represent a service area that would be as cost-effective to serve as a single large user. Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed path of the transmission system.

The value of reclaimed water – even to an "obvious" potential user will depend on the:

- Quality of water to be provided, as compared to the user's requirements
- Quantity of fresh water available and the ability to meet fluctuating demand
- Effects of laws that regulate reuse, and the attitudes of agencies responsible for enforcing applicable laws
- Present and projected future cost of fresh water to the user

These questions all involve detailed study, and it may not be cost-effective for public entities to apply the required analyses to every possible reuse scenario. A useful first step is to identify a wide range of candidate reuse systems that might be suitable in the area and to screen these alternatives. Then, only the most promising project candidates move forward with detailed evaluations.

In order to establish a comprehensive list of reuse possibilities, the following factors should be taken into account:

- Levels of treatment – if advanced wastewater treatment (AWT) is currently required prior to discharge of effluent, cost savings might be available if a market exists for secondary treated effluent.
- Project size – the scale of reuse can range from conveyance of reclaimed water to a single user up to the general distribution of reclaimed water for a variety of nonpotable uses.
- Conveyance network – different distribution routes will have different advantages, taking better advantage of existing rights-of-way, for example, or serving a greater number of users.

In addition to comparing the overall costs estimated for each alternative, several other criteria can be factored into the screening process. Technical feasibility may be used as one criterion, and the comparison of estimated unit costs of reclaimed water with unit costs of fresh water, as another. An even more complex screening process may include a comparison of weighted values for a variety of objective and subjective factors, such as:

- How much flexibility would each system offer for future expansion or change?
- How much fresh water use would be replaced by each system?
- How complicated would program implementation be, given the number of agencies that would be involved in each proposed system?
- To what degree would each system advance the "state-of-the-art" in reuse?
- What level of chemical or energy use would be associated with each system?
- How would each system impact land use in the area?

Review of user requirements could enable the list of potential markets to be reduced to a few selected markets for which reclaimed water could be of significant value. The Bay Area Regional Water Recycling Program (BARWRP) in San Francisco, California used a sophisticated screening and alternative analysis procedure. This included use of a regional GIS-based market assessment, a computer model to evaluate cost-effective methods for delivery, detailed evaluation criteria, and a spreadsheet-based evaluation decision methodology (Bailey *et al.,* 1998). The City of Tucson, Arizona, also used a GIS database to identify parcels such as golf courses, parks, and schools with a potential high demand for turf irrigation. In Cary, North Carolina, the parcel database was joined to the customer-billing database allowing large water users to be displayed on a GIS map. This process was a key element in identifying areas with high concentrations of dedicated irrigation meters on the potable water system (CDM, 1997). As part of an evaluation of water reclamation by the Clark County Sanitation District, Nevada, the alternatives analysis was extended beyond the traditional technical, financial, and regulatory considerations to include intangible criteria such as:

- Public acceptance including public education
- Sensitivity to neighbors
- Administrative agencies for the project
- Institutional arrangements to implement
- Impacts to existing developments as facilities are constructed

Source: Pai *et. al.,* 1996

3.1.3 Detailed Evaluation of Selected Markets

The evaluation steps contained in this phase represent the heart of the analyses necessary to shape a reuse program. At this point, a certain amount of useful data should be known including the present freshwater consumption and costs for selected potential users and a ranking of "most-likely" projects. In this phase, a more detailed look at conveyance routes and storage requirements for each selected system will help to refine preliminary cost estimates. Funding and benefit options can be compared, user costs developed, and a comparison made between the costs and benefits of fresh water versus reclaimed water for each selected system. The detailed evaluation will also look in more detail at the environmental, institutional, and social aspects of each project.

Questions that may need to be addressed as part of the detailed evaluation include:

- What are the specific water quality requirements of each user? What fluctuation can be tolerated?
- What is the daily and seasonal water use demand pattern for each potential user?
- Can fluctuations in demand best be met by pumping capacity or by using storage? Where would storage facilities best be located?
- If additional effluent treatment is required, who should own and operate the additional treatment facilities?
- What costs will the users in each system incur in connecting to the reclaimed water delivery system?
- Will industrial users in each system face increased treatment costs for their waste streams as a result of using reclaimed water? If so, is increased internal recycling likely, and how will this affect their water use?
- Will customers in the service area allow project costs to be spread over the entire service area?
- What interest do potential funding agencies have in supporting each type of reuse program being considered? What requirements would these agencies impose on a project eligible for funding?
- Will use of reclaimed water require agricultural users to make a change to their irrigation patterns or to provide better control of any irrigation discharges?
- What payback period is acceptable to users who must invest in additional facilities for onsite treatment, storage, or distribution of reclaimed water?
- What are the prospects of industrial source control measures in the area, and would institution of such measures reduce the additional treatment steps necessary to permit reuse?
- How "stable" are the potential users in each selected candidate reuse system? Are they likely to remain in their present locations? Are process changes being considered that might affect their ability to use reclaimed water?

Many of these questions can be answered only after further consultation with water supply agencies and prospective users. Both groups may seek more detailed information as well, including the preliminary findings made in the first 2 phases of effort. The City of Tampa set the following goals and objectives for their first residential reclaimed water project:

- Demonstrate customer demand for the water
- Demonstrate customer willingness to pay for the service
- Show that the project would pay for itself and not be subsidized by any utility customer not receiving reclaimed water
- Make subscription to the reclaimed water service voluntary

Source: Grosh *et. al.,* 2002

Detailed evaluations should lead to a preliminary assessment of technical feasibility and costs. Comparison among alternative reuse programs will be possible, as well as preliminary comparison between these programs and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical optimization steps, and environmental assessment activities leading to a conceptual plan for reuse might be accomplished by working in conjunction with appropriate consulting organizations.

3.2 Potential Uses of Reclaimed Water

Urban public water supplies are treated to satisfy the requirements for potable use. However, potable use (drinking, cooking, bathing, laundry, and dishwashing) represents only a fraction of the total daily residential use of treated potable water. The remainder may not require water of potable quality. In many cases, water used for nonpotable purposes, such as irrigation, may be drawn from the same ground or surface source as municipal supplies, creating an indirect demand on potable supplies. The *Guidelines* examine opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. Specific reuse opportunities include:

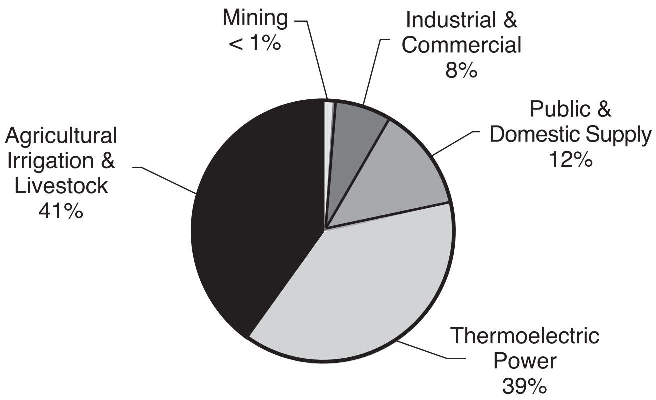
- Urban
- Industrial
- Agricultural
- Environmental and Recreational
- Groundwater Recharge
- Augmentation of Potable Supplies

The technical issues associated with the implementation of each of these reuse alternatives are discussed in detail in Chapter 2. The use of reclaimed water to provide both direct and indirect augmentation of potable supplies is also presented in Chapter 2.

3.2.1 National Water Use

Figure 3-2 presents the national pattern of water use in the U.S. according to the U.S. Geological Survey (Solley *et al.,* 1998). Total water use in 1995 was 402,000 mgd (152 x 10^7 m^3/d) with 341,000 mgd (129 x 10^7 m^3/d) being fresh water and 61,000 mgd (23 x 10^7 m^3/d) saline water. The largest freshwater demands were associated with agricultural irrigation/livestock and thermoelectric power, representing 41 and 39 percent, respectively, of the total freshwater use in the United States. Public and domestic water uses constitute 12 percent of the total demand.

Figure 3-2. 1995 U.S. Fresh Water Demands by Major Uses



Source: Solley *et. al*., 1998

The remainder of the water use categories are mining and industrial/commercial with 8 percent of the demand. The 2 largest water use categories, thermoelectric power and agricultural irrigation, account for 80 percent of the total water use. These water uses present a great potential for supplementing with reclaimed water.

Figure 3-3 provides a flow chart illustrating the source, use, and disposition of fresh water in the U.S. Of the 341,000 mgd (129 x 10^7 m^3/d) of fresh water used in the U.S., only 29 percent is consumptively used and 71 percent is return flow. This amounts to a total of 241,000 mgd (91 x 10^7 m^3/d), of which 14 percent originates from domestic and commercial water use. Domestic wastewater comprises a large portion of this number.

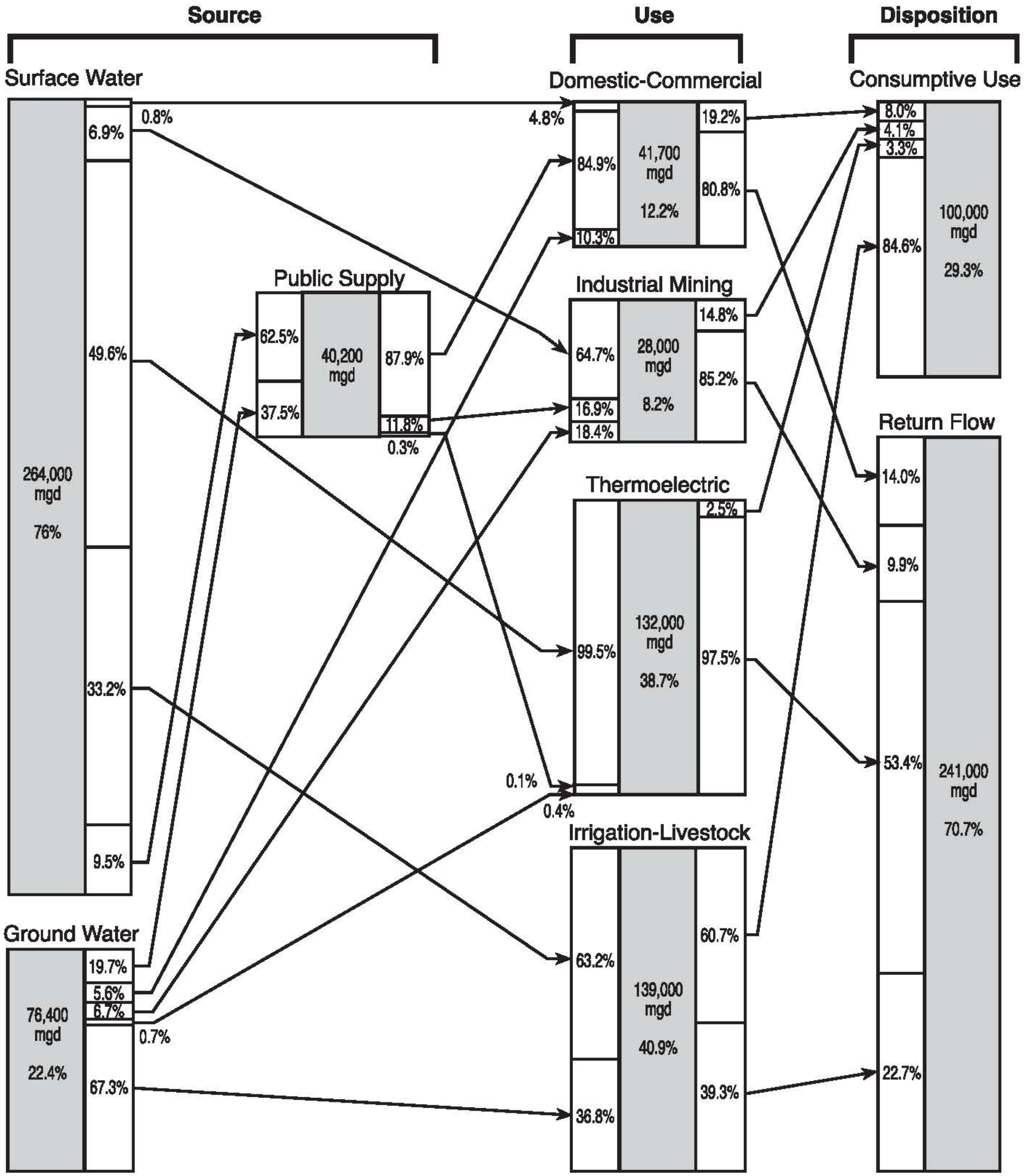
Figure 3-4 shows estimated wastewater effluent produced daily in each state, representing the total potential reclaimed water supply from existing wastewater treatment facilities. **Figure 3-5** shows the estimated water demands by state in the United States. Estimated water demands are equal to the total fresh and saline withdrawals for all water-use categories (public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power). Areas where high water demand exists might benefit by augmenting existing water supplies with reclaimed water. Municipalities in coastal and arid states, where water demands are high and freshwater supplies are limited, appear to have a reasonable supply of wastewater effluent that could, through proper treatment and reuse, greatly extend their water supplies.

Arid regions of the U.S. (such as the southwest) are candidates for wastewater reclamation, and significant reclamation projects are underway throughout this region. Yet, arid regions are not the only viable candidates for water reuse. Local opportunities may exist for a given municipality to benefit from reuse by extending local water supplies and/or reducing or eliminating surface water discharge. For example, the City of Atlanta, Georgia, located in the relatively water-rich southeast, has experienced water restrictions as a result of recurrent droughts. In south Florida, subtropical conditions and almost 55 inches (140 cm) per year of rainfall suggest an abundance of water; however, landscaping practices and regional hydrogeology combine to result in frequent water shortages and restrictions on water use. Thus, opportunities for water reclamation and reuse must be examined on a local level to judge their value and feasibility.

3.2.2 Potential Reclaimed Water Demands

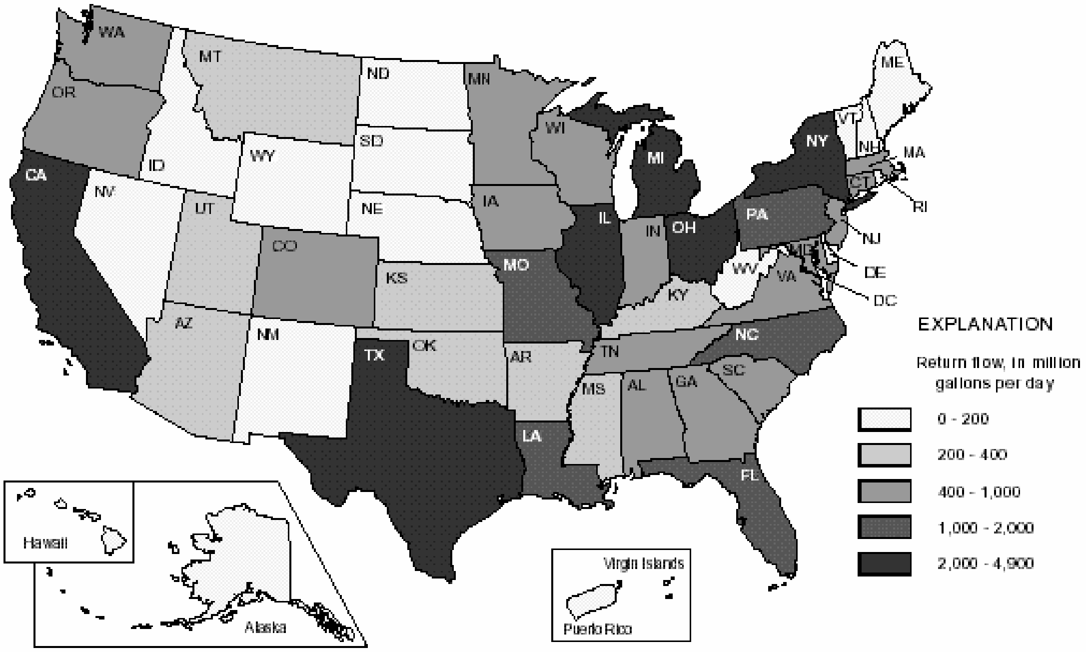
Residential water demand can further be categorized as indoor use, which includes toilet flushing, cooking, laundry, bathing, dishwashing, and drinking; or outdoor use,

Figure 3-3. **Fresh Water Source, Use and Disposition**



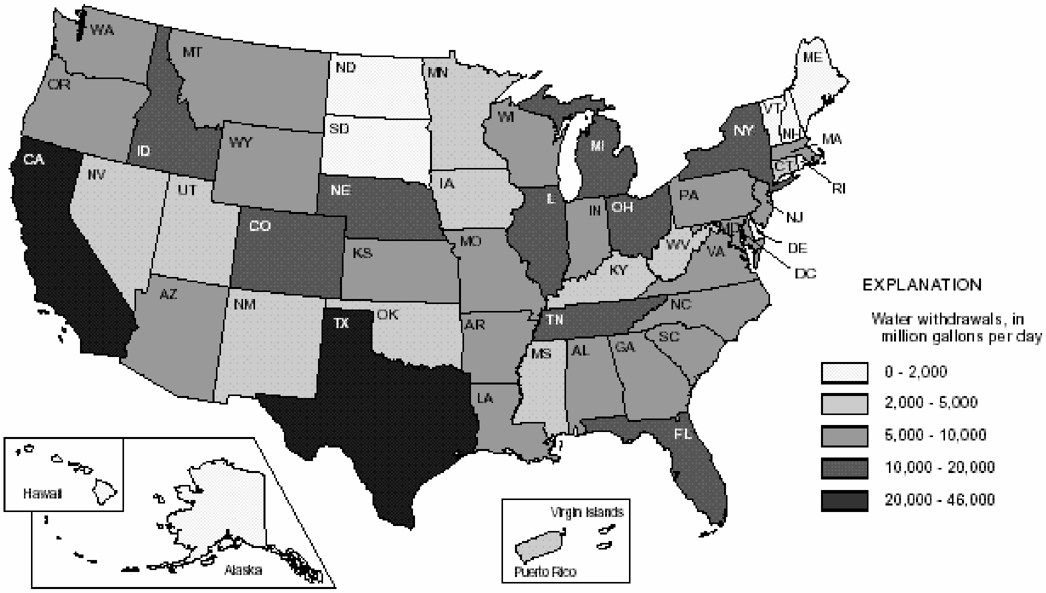
Source: Solley *et. al.*, 1998

Figure 3-4. Wastewater Treatment Return Flow by State, 1995



Source: Solley *et al.*, 1998

Figure 3-5. Total Withdrawals



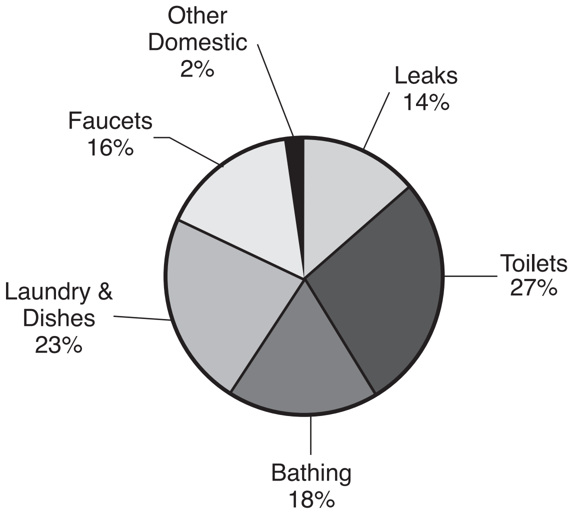
Source: Solley *et al.*, 1998

which consists primarily of landscape irrigation. Outdoor use accounts for approximately 31 percent of the residential demand, while indoor use represents approximately 69 percent (Vickers, 2001). **Figure 3-6** presents the average residential indoor water use by category. It should be noted that these are national averages, and few residential households will actually match these figures. Inside the home, the largest use of water is toilet flushing (almost 30 percent). The potable use (cooking, drinking, bathing, laundry, and dishwashing) represents about 60 percent of the indoor water use or about 40 percent of the total residential (outdoor and indoor) demand. Reclaimed water could be used for all nonpotable uses (toilet flushing and outdoor use), which are approximately 50 percent of the total residential water demand. Leaks are neglected in these calculations.

Approximately 38 billion gallons of water is produced daily in the U.S. for domestic and public use. On average, a typical American household consumes at least 50 percent of their water through lawn irrigation. The U.S. has a daily requirement of 40 billion gallons (152 million m^3) a day of fresh water for general public use. This requirement does not include the 300 billion gallons (1,135 million m^3) used for agricultural and commercial purposes. For example, a dairy cow must consume 4 gallons (15 l) of water to produce 1 gallon (4 l) of milk, and it takes 300 million gallons (1.1 million m^3) of water to produce a 1-day supply of U.S. newsprint (American Water Works Association Website, 2003).

The need for irrigation is highly seasonal. In the North where turf goes dormant, irrigation needs will be zero in the winter months. However, irrigation demand may represent a significant portion of the total potable water demand in the summer months. In coastal South Carolina, winter irrigation use is estimated to be less than 10 percent of the total potable demand. This increases to over 30 percent in the months of June and July. In Denver, during July and August when temperatures exceed 90 °F (32 °C), approximately 80 percent of all potable water may be used for irrigation. Given the seasonal nature of urban irrigation, eliminating this demand from the potable system through reuse will result in a net annual reduction in potable demands and, more importantly, may also significantly reduce peak-month potable water demands.

Figure 3-6. **Average Indoor Water Usage (Total = 69.3 gpcd)**



Source: Vickers, 2001

It is not surprising then that landscape irrigation currently accounts for the largest urban use of reclaimed water in the U.S. This is particularly true of urban areas with substantial residential areas and a complete mix of landscaped areas ranging from golf courses to office parks to shopping malls. Urban areas also have schools, parks, and recreational facilities, which require regular irrigation. Within Florida, for example, studies of potable water consumption have shown that 50 to 70 percent of all potable water produced is used for outside purposes, principally irrigation.

The potential irrigation demand for reclaimed water generated by a particular urban area can be estimated from an inventory of the total irrigable acreage to be served by the reuse system and the estimated weekly irrigation rates, determined by factors such as local soil characteristics, climatic conditions, and type of landscaping. In some states, recommended weekly irrigation rates are available from water management agencies, county or state agricultural agents, and irrigation specialists. Reclaimed water demand estimates should also take into account any other proposed uses for reclaimed water within the proposed service area, such as industrial cooling and process water, decorative fountains, and other aesthetic water features.

Agricultural irrigation represents 40 percent of total water demand nationwide and presents another significant opportunity for water reuse, particularly in areas where agricultural sites are near urban areas and can easily be integrated with urban reuse applications. Such is the case in Orange County, California, where the Irvine Ranch Water District provides reclaimed water to irrigate urban landscape and mixed agricultural lands (orchards and vegetable row crops). As agricultural land use is displaced by residential development in this growing urban area, the District has the flexibility to convert its reclaimed water service to urban irrigation.

In Manatee County, Florida, agricultural irrigation is a significant component of a county-wide water reuse program. During 2002, the County's 3 water reclamation facilities, with a total treatment capacity of 34.4 mgd (1,500 l/s), provided about 10.2 mgd (446 l/s) of reclaimed water. This water was used to irrigate golf courses, parks, schools, residential subdivisions, a 1,500-acre (600-hectare) gladioli farm, and about 6,000 acres (2,400 hectares) of mixed agricultural lands (citrus, ridge and furrow crops, sod farms, and pasture). The original 20-year reuse agreements with the agricultural users are being extended for 10 years, ensuring a long-term commitment to reclaimed water with a significant water conservation benefit. The urban reuse system has the potential to grow as development grows. Manatee County has more than 385 acres (154 hectares) of lake storage (1,235 million gallons or 47 x 10^5 m^3 of volume) and 2 reclaimed water aquifer storage and recovery (ASR) projects.

A detailed inspection of existing or proposed water use is essential for planning any water reuse system. This information is often available through municipal billing records or water use monitoring data that is maintained to meet the requirements of local or regional water management agencies. In other cases, predictive equations may be required to adequately describe water demands. Water needs for various reuse alternatives are explored further in Chapter 2. In addition to expected nonpotable uses for reclaimed water, a review of literature shows consideration and implementation of reuse projects for a wide variety of demands including toilet flushing, commercial car washing, secondary and primary sources of fire protection, textile mills to maintain water features, cement manufacturing, and make-up water for commercial air conditioners. By identifying and serving a variety of water uses with reclaimed water, the utilization of reclaimed water facilities can be increased, thereby increasing the cost effectiveness of the system while at the same time increasing the volume of potable water conserved.

3.2.3 Reuse and Water Conservation

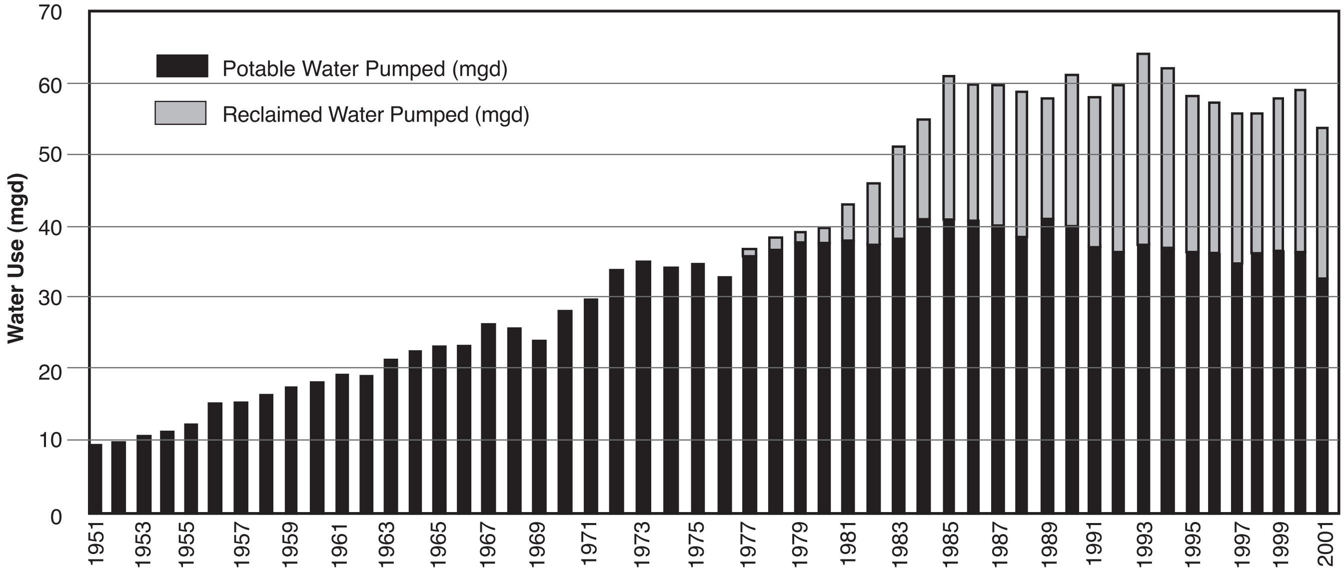
The need to conserve the potable water supply is an important part of urban and regional planning. For example, the Metropolitan Water District of Southern California predicted in 1990 that by the year 2010 water demands would exceed reliable supplies by approximately 326 billion gallons (1,200 x 10^9 m^3) annually (Adams, 1990). To help conserve the potable water supplies, the Metropolitan Water District developed a multi-faceted program that includes conservation incentives, rebate programs, groundwater storage, water exchange agreements, reservoir construction, and reclaimed water projects. Urban reuse of reclaimed water is an essential element of the program. In 2001, approximately 62 billion gallons (330 x 10^6 m^3) of reclaimed water were used in the District's service area for groundwater recharge, landscape irrigation, agricultural, commercial, and industrial purposes. It is estimated that more than 195 billion gallons (740 x 10^6 m^3) of reclaimed water will be reused by 2010. Due to long-term conservation programs, additional supply agreements, and an increase in the reclaimed water supply the District expects to meet the area's water needs for the next ten years even during times of critical drought (Metropolitan, 2002).

Perhaps the greatest benefit of urban reuse systems is their contribution to delaying or eliminating the need to expand potable water supply and treatment facilities. The City of St. Petersburg, Florida, has experienced about a 10 percent population growth since 1976 without any significant increase in potable water demand because of its urban reuse program. Prior to the start-up of its urban reuse system, the average residential water demand in a study area in St. Petersburg was 435 gallons per day (1,650 l/d). After reclaimed water was made available, the potable water demand was reduced to 220 gallons per day (830 l/d) (Johnson and Parnell, 1987). **Figure 3-7** highlights the City of St. Petersburg's estimated potable water savings since implementing an urban reuse program.

In 2001, Florida embarked on the *Water Conservation Initiative* (FDEP, 2002) – a program designed to promote water conservation in an effort to ensure water availability for the future. Recognizing the conservation and recharge potential of water reuse, a Water Reuse Work Group was convened to address the effective and efficient use of reclaimed water as a component in overall strategies to ensure water availability. The Water Reuse Work Group published its initial report in 2001 (FDEP, 2001) and published a more detailed strategy report in 2003 (FDEP, 2003). The final reuse strategy report includes 16 major strategies designed to ensure efficient and effective water reuse. Of particular note are strategies that encourage the use of reclaimed water meters and volume-based rates, in addition to encouraging groundwater recharge and indirect potable reuse.

Currently, approximately 20 percent of all water supplied by the Irvine Ranch Water District in southern California is reclaimed water. Total water demand is expected to reach 69 mgd (3,024 l/s) in Irvine by 2010. At that time Irvine expects to be able to provide service to meet approximately 26 mgd (1,139 l/s) of this demand with reclaimed water (Irvine Ranch Water District, 2002). An aggressive urban reuse program in Altamonte Springs, Florida is credited with a 30 percent reduction in potable water demands (Forest *et al.,* 1998).

Figure 3-7. Potable and Reclaimed Water Usage in St. Petersburg, Florida



3.3 Sources of Reclaimed Water

Under the broad definition of water reclamation and reuse, sources of reclaimed water may range from industrial process waters to the tail waters of agricultural irrigation systems. For the purposes of these guidelines, however, the sources of reclaimed water are limited to the effluent generated by domestic wastewater treatment facilities (WWTFs).

Treated municipal wastewater represents a significant potential source of reclaimed water for beneficial reuse. As a result of the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977 and its subsequent amendments, centralized wastewater treatment has become commonplace in urban areas of the U.S. In developed countries, approximately 73 percent of the population is served by wastewater collection and treatment facilities. Yet only 35 percent of the population of developing countries is served by wastewater collection. Within the U.S., the population generates an estimated 41 billion gallons per day (1.8 x 106 l/s) of potential reclaimed water (Solley *et al*., 1998). As the world population continues to shift from rural to urban, the number of centralized wastewater collection and treatment systems will also increase, creating significant opportunities to implement water reuse systems to augment water supplies and, in many cases, improve the quality of surface waters.

3.3.1 Locating the Sources

In areas of growth and new development, completely new collection, treatment, and distribution systems may be designed from the outset with water reclamation and reuse in mind. In most cases, however, existing facilities will be incorporated into the water reuse system. In areas where centralized treatment is already provided, existing WWTFs are potential sources of reclaimed water.

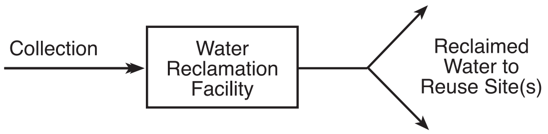
In the preliminary planning of a water reuse system incorporating existing facilities, the following information is needed for the initial evaluation:

- Residential areas and their principal sewers
- Industrial areas and their principal sewers
- Wastewater treatment facilities
- Areas with combined sewers
- Existing effluent disposal facilities
- Areas and types of projected development
- Locations of potential reclaimed water users

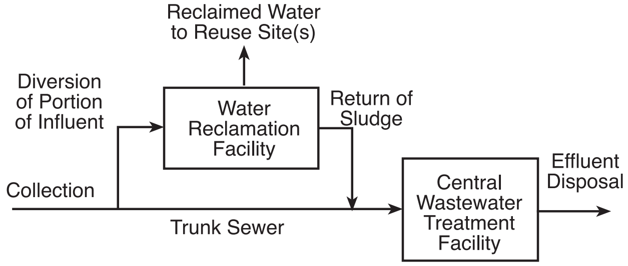
For minimizing capital costs, the WWTFs ideally should be located near the major users of the reclaimed water. However, in adapting an existing system for water reuse, other options are available. For example, if a trunk sewer bearing flows to a WWTF passes through an area of significant potential reuse, a portion of the flows can be diverted to a new “satellite” reclamation facility to serve that area. The sludge produced in the satellite reclamation facility can be returned to the sewer for handling at the WWTF. By this method, odor problems may be reduced or eliminated at the satellite reclamation facility. However, the effects of this practice can be deleterious to both sewers and downstream treatment facilities. Alternatively, an effluent outfall passing through a potential reuse area could be tapped for some or all of the effluent, and additional treatment could be provided, if necessary, to meet reclaimed water quality standards. These alternative configurations are illustrated in **Figure 3-8.**

Figure 3-8. Three Configuration Alternatives for Water Reuse Systems

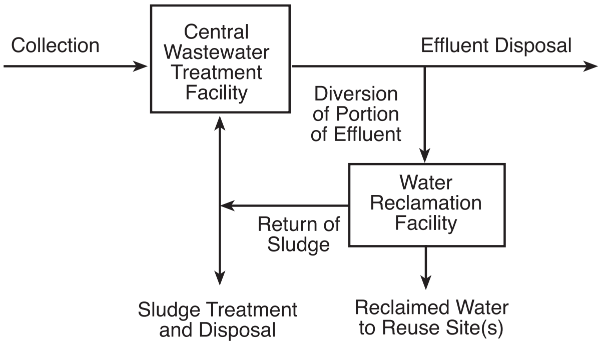
A. Central Treatment Near Reuse Site(s)



B. Reclamation of Portion of Wastewater Flow



C. Reclamation of Portion of Effluent



3.3.2 Characterizing the Sources

Existing sources must be characterized to roughly establish the wastewater effluent’s suitability for reclamation and reuse. To compare the quality and quantity of available reclaimed water with the requirements of potential users, information about the operation and performance of the existing WWTF and related facilities must be examined. Important factors to consider in this preliminary stage of reuse planning are:

- Level of treatment (e.g., primary, secondary, advanced) and specific treatment processes (e.g., ponds, activated sludge, filtration, disinfection, nutrient removal, disinfection)
- Effluent water quality
- Effluent quantity (use of historical data to determine daily and season at average, maximum, and minimum flows)
- Industrial wastewater contributions to flow
- System reliability
- Supplemental facilities (e.g., storage, pumping, transmission)

3.3.2.1 Level of Treatment and Processes

Meeting all applicable treatment requirements for the production of safe, reliable reclaimed water is one of the keys to operating any water reuse system. Thus careful analysis of applicable state and local requirements and provision of all necessary process elements are critical in designing a reuse system. Because of differing environmental conditions from region to region across the country, and since different end uses of the reclaimed water require different levels of treatment, a universal quality standard for reclaimed water does not exist. In the past, the main objective of treatment for reclaimed water was secondary treatment and disinfection. As wastewater effluent is considered a source for more and more uses, such as industrial process water or even potable supply water, the treatment focus has expanded beyond secondary treatment and disinfection to include treatment for other containments such as metals, dissolved solids, and emerging contaminants (such as pharmaceutical residue and endocrine disruptors). However, at this early planning stage, only a preliminary assessment of the compatibility of the secondary effluent quality and treatment facilities with potential reuse applications is needed. A detailed discussion of treatment requirements for water reuse applications is provided in Section 3.4.

Knowledge of the chemical constituents in the effluent, the level of treatment, and the treatment processes provided is important in evaluating the WWTF's suitability as a water reclamation facility and determining possible reuse applications. An existing plant providing at least secondary treatment, while not originally designed for water reclamation and reuse, can be upgraded by modifying existing processes or adding new unit processes to the existing treatment train to supply reclaimed water for most uses. For example, with the addition of chemicals, filters, and other facilities to ensure reliable disinfection, most secondary effluents can be enhanced to provide a source of reclaimed water suitable for unrestricted urban reuse. However, in some parts of the U.S., the effluent from a secondary treatment system may contain compounds of concern. Such effluent may not be used because it could result in water quality problems. In these cases, treatment processes must be selected to reduce these compounds before they are released. This can create additional disposal issues as well. A typical example would be the presence of elevated TDS levels within the effluent, resulting in problems where the reclaimed water is used for irrigation (Sheikh *et al.*, 1997; Dacko, 1997; Johnson, 1998).

In some cases, existing processes necessary for effluent disposal practices may no longer be required for water reuse. For example, an advanced wastewater treatment plant designed to remove nitrogen and/or phosphorus would not be needed for agricultural or urban irrigation, since the nutrients in the reclaimed water are beneficial to plant growth.

In addition to the unit processes required to produce a suitable quality of reclaimed water, the impact of any return streams (e.g., filter backwash, RO concentrate return, etc.) to the WWTF's liquid and solids handling processes should be considered.

3.3.2.2 Reclaimed Water Quality

Effluent water quality sampling and analysis are required as a condition of WWTF discharge permits. The specific parameters tested are those required for preserving the water quality of the receiving water body, (*e.g.,* biochemical oxygen demand, suspended solids, coliforms or other indicators, nutrients, and sometimes toxic organics and metals). This information is useful in the preliminary evaluation of a wastewater utility as a potential source of reclaimed water. For example, as noted earlier, the nitrogen and phosphorus in reclaimed water represents an advantage for certain irrigation applications. For industrial reuse, however, nutrients may encourage biological growths that could cause fouling. Where the latter uses are a small fraction of the total use, the customer may be obliged to remove the nutrients or blend reclaimed water with other water sources. The decision is based on case-by-case assessments.

In some cases, the water quality data needed to assess the suitability of a given source are not included in the WWTF's existing monitoring requirements and will have to be gathered specifically for the reuse evaluation. Coastal cities may experience saltwater infiltration into their sewer system, resulting in elevated chloride concentrations in the effluent or reclaimed water. Chloride levels are of concern in irrigation because high levels are toxic to many plants. However, chloride levels at WWTFs typically are not monitored. Even in the absence of saltwater infiltration, industrial contributions or practices within the community being served may adversely impact reclaimed water quality. The widespread use of water softeners may increase the concentration of salts to levels that make the reclaimed water unusable for some applications. High chlorides from saltwater infiltration led the City of Punta Gorda, Florida to cease reclaimed water irrigation in 2001. This facility had irrigated an underdrained agricultural site for almost 20 years, but flow discharged from the underdrains caused a violation of conductivity limitations in the receiving water.

Damage to landscape plants in the City of St. Petersburg, Florida, was traced to elevated chlorides in the reclaimed water. This coastal city operates 4 reclamation plants and those serving older beach communities are prone to saltwater infiltration. In response to this problem, the City initiated on-line monitoring of conductance in order to identify and halt the use of unacceptable water. The City also developed a planting guide for reclaimed water customers to identify foliage more and less suitable for use with reclaimed water service (Johnson, 1998). The Carmel Area Wastewater District in California experienced a similar problem with golf course turf associated with elevated sodium. This was due to a combination of the potable water treatment processes being used, and the prevalence of residential and commercial water softeners. Solutions included the use of gypsum, periodic use of potable water for irrigation to flush the root zone, a switch from sodium hydroxide to potassium hydroxide for corrosion control, and attempts to reduce the use of self-regenerating water softeners (Sheikh *et al.,* 1997). Some coastal communities, or areas where salinity is a concern, have begun to restrict the discharge of chemical salts into the sanitary sewer system either by requiring their placement in a special brine line or by charging a fee for their treatment and removal (Sheikh and Rosenblum, 2002). A California state law recently gave local jurisdictions the ability to prohibit the use of self-regenerating water softeners that had been previously exempt from regulation by a prior statute (California Health and Safety Code).

The West Basin Municipal Water District in southwest Los Angeles County, California, created designer reclaimed water of different qualities to increase their reclaimed water customer base. **Table 3-1** describes the 5 different grades of designer water they produce and supply to their 200-square mile area of customers.

For the purpose of reuse planning, it is best to consider reclaimed water quality from the standpoint of water supply, (i.e., what quality is required for the intended use?). Where a single large customer dominates the demand for reclaimed water, the treatment selected may suit that particular, major customer. In Pomona, California, activated carbon filters were used in place of conventional sand filters at the reclamation plant to serve paper mills that require low color in their water supply.

Industrial reuse might be precluded if high levels of dissolved solids, dissolved organic material, chlorides, phosphates, and nutrients are present, unless additional treatment is provided by the industrial facility. Recreational reuse might be limited by nutrients, which could result in unsightly and odorous algae blooms. Trace metals in high concentrations might restrict the use of reclaimed water for agricultural and horticultural irrigation.

3.3.2.3 Reclaimed Water Quantity

Just as the potable water purveyor must meet diurnal and seasonal variations in demand, so too must the purveyor meet variations in demand for reclaimed water. Diurnal and seasonal fluctuations in supply and demand must be taken into account at the preliminary design stage of any water reclamation system. Such an approach is warranted, given the fact that diurnal and seasonal supplies and demands for reclaimed water often exhibit more variations than that of potable water and, in many cases, the peaks in supply and demand are independent of one another.

For example, WWTF flows tend to be low at night, when urban irrigation demand tends to be high. Seasonal flow fluctuations may occur in resort areas due to the influx

Table 3-1. Five Grades of Reclaimed Water Produced by West Basin MWD

Grade	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Name	Tertiary	Nitrified	Pure RO	Softened RO	Ultra-Pure RO
Treatment	Secondary effluent; additional filtration and disinfection	Tertiary water with ammonia removal	Secondary water plus micro filtration and RO	Grade 3 plus lime softening treatment	Double pass RO
Use	Landscape; golf course irrigation	Cooling towers	Low pressure boiler feed for refineries	Indirect potable reuse for the Water Replenishment District	High pressure boiler feed for refineries
Quality Drivers	Human contact and health requirements	Need to remove ammonia to reduce corrosion	Need to reduce contaminants that cause scaling; strong desire to use the water multiple times in the process	Softening the water preserves the pipes that deliver the water to the injection wells. Micro-filtration and RO have been perceived as providing acceptable treatment for indirect potable reuse.	High pressure increases the need to further reduce contaminants that cause scaling. Desire to use the water multiple times in the process
Reliability	No contractual guarantee; 100% reliable due to constant source	No information provided	No contractual guarantees	No contractual guarantees. May be perceived as more reliable	No contractual guarantees. Probably perceived as more reliable
Price	25 - 40% discount from baseline standard	Approximately 20% discounted from baseline standard	Equal to baseline standard or slightly higher	20% discount from baseline standard	100% price premium compared to the baseline standard
2001-02 Volume (AF)	2,600	8,300	6,500	7,300	2,600

Adapted from: "West Basin Municipal Water District: 5 Designer (Recycled) Waters to Meet Customer's Needs" produced by Darryl G. Miller, General Manager, West Basin Municipal Water District, Carson, California.

of tourists, and seasons of high flow do not necessarily correspond with seasons of high irrigation demand. **Figure 3-9** illustrates the fluctuations in reclaimed water supply and irrigation demand in a southwest Florida community. Treatment facilities serving college campuses, resort areas, etc. also experience significant fluctuations in flow throughout the year. Where collection systems are prone to infiltration and inflow, significant fluctuations in flow may occur during the rainy season.

Information about flow quantities and fluctuations is critical in order to determine the size of storage facilities needed to balance supply and demand in water reuse systems. A more detailed discussion of seasonal storage requirements is provided in Section 3.5. Operational storage requirements to balance diurnal flow variations are detailed in Section 3.6.3.

3.3.2.4 Industrial Wastewater Contributions

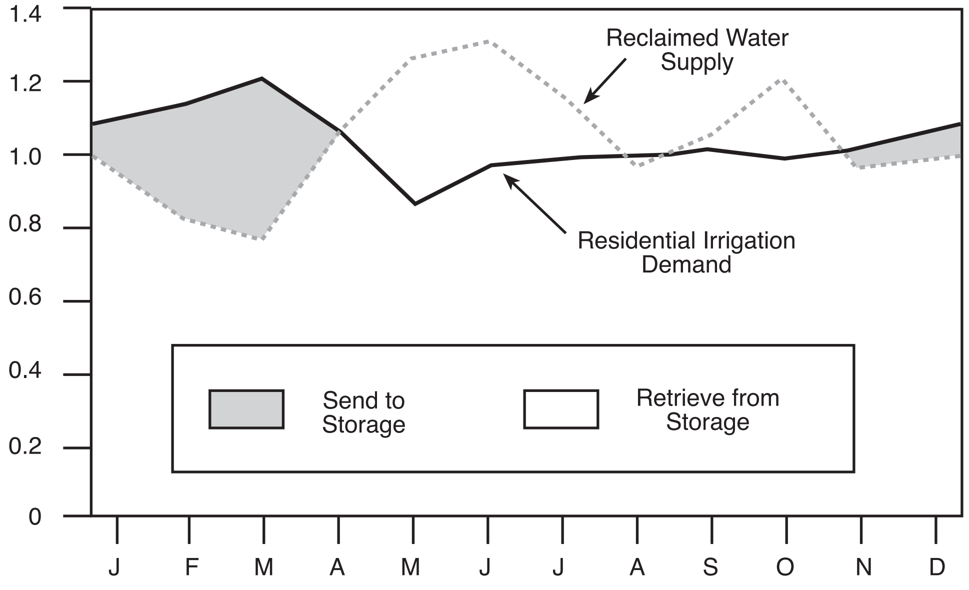
Industrial waste streams differ from domestic wastewater in that they may contain relatively high levels of elements and compounds, which may be toxic to plants and animals or may adversely impact treatment plant performance. Where industrial wastewater flow contributions to the WWTF are significant, reclaimed water quality may be affected. The degree of impact will, of course, depend on the nature of the industry. A rigorous pretreatment program is required for any water reclamation facility that receives industrial wastes to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Planning a reuse system for a WWTF with substantial industrial flows will require identification of the constituents that may interfere with particular reuse applications, and appropriate monitoring for parameters of concern. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

3.4 Treatment Requirements for Water Reuse

One of the most critical objectives in any reuse program is to ensure that public health protection is not compromised through the use of reclaimed water. To date there have not been any confirmed cases of infectious disease resulting from the use of properly treated reclaimed water in the U.S. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied, but the starting point remains the safe delivery and use of properly treated reclaimed water.

Protection of public health is achieved by: (1) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water, (2) controlling chemical constituents in reclaimed water, and/or (3) limiting public exposure (contact, inhalation, ingestion) to reclaimed water. Reclaimed water projects may vary significantly in the level of human exposure incurred, with a corresponding variation in the potential for health risks. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to

Figure 3-9. Reclaimed Water Supply vs. Irrigation Demand



a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised.

Determining the necessary treatment for the intended reuse application requires an understanding of the:

- Constituents of concern in wastewater
- Levels of treatment and processes applicable for reducing these constituents to levels that achieve the desired reclaimed water quality

3.4.1 Health Assessment of Water Reuse

The types and concentrations of pathogenic organisms found in raw wastewater are a reflection of the enteric organisms present in the customer base of the collection system. Chemical pollutants of concern may also be present in untreated wastewater. These chemicals may originate from any customer with access to the collection system, but are typically associated with industrial customers. Recent studies have shown that over-the-counter and prescription drugs are often found in wastewater.

The ability for waterborne organisms to cause disease is well established. Our knowledge of the hazards of chemical pollutants varies. In most cases, these concerns are based on the potential that adverse health effects may occur due to long-term exposure to relatively low concentrations. In addition, chemicals capable of mimicking hormones have been shown to disrupt the endocrine systems of aquatic animals.

In order to put these concerns into perspective with respect to water reclamation, it is important to consider the following questions.

- What is the intended use of the reclaimed water?

  Consideration should be given to the expected degree of human contact with the reclaimed water. It is reasonable to assume that reclaimed water used for the irrigation of non-food crops on a restricted agricultural site may be of lesser quality than water used for landscape irrigation at a public park or school, which in turn may be of a lesser quality than reclaimed water intended to augment potable supplies.

- Given the intended use of reclaimed water, what concentrations of microbiological organisms and chemicals of concern are acceptable?

  Reclaimed water quality standards have evolved over a long period of time, based on both scientific studies and practical experience. Chapter 4 provides a summary of state requirements for different types of reuse projects. While requirements might be similar from state to state, allowable concentrations and the constituents monitored are state-specific. Chapter 4 also provides suggested guidelines for reclaimed water quality as a function of use.

- Which treatment processes are needed to achieve the required reclaimed water quality?

  While it must be acknowledged that raw wastewater may pose a significant risk to public health, it is equally important to point out that current treatment technologies allow water to be treated to almost any quality desired. For many uses of reclaimed water, appropriate water quality can be achieved through conventional, widely practiced treatment processes. Advanced treatment beyond secondary treatment may be required as the level of human contact increases.

- Which sampling/monitoring protocols are required to ensure that water quality objectives are being met?

  As with any process, wastewater reuse programs must be monitored to confirm that they are operating as expected. Once a unit process is selected, there are typically standard Quality Assurance/Quality Control (QA/QC) practices to assure that the system is functioning as designed. Reuse projects will often require additional monitoring to prevent the discharge of substandard water to the reclamation system. On-line, real-time water quality monitoring is typically used for this purpose.

3.4.1.1 Mechanism of Disease Transmission

For the purposes of this discussion, the definition of disease is limited to illness caused by microorganisms. Health issues associated with chemical constituents in reclaimed water are discussed in Section 3.4.1.7. Diseases associated with microorganisms can be transmitted by water to humans either directly by ingestion, inhalation, or skin contact of infectious agents, or indirectly by contact with objects or individuals previously contaminated. The following circumstances must occur for an individual to become infected through exposure to reclaimed water: (a) the infectious agent must be present in the community and, hence, in the wastewater from that community; (b) the agents must survive, to a significant degree, all of the wastewater treatment processes to which they are exposed; (c) the individual must either directly or indirectly come into contact with the reclaimed water; and (d) the agents must be present in sufficient numbers to cause infection at the time of contact.

The primary means of ensuring reclaimed water can be used for beneficial purposes is first to provide the appropriate treatment to reduce or eliminate pathogens. Treatment processes typically employed in water reclamation systems are discussed below and in Section 3.4.2. Additional safeguards are provided by reducing the level of contact with reclaimed water. Section 3.6 discusses a variety of cross-connection control measures that typically accompany reuse systems.

The large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected humans and primarily transmitted by consumption. Thus, the main transmission route is referred to as the "fecal-oral" route. Contaminated water is an important conduit for fecal-oral transmission to humans and occurs either by direct consumption or by the use of contaminated water in agriculture and food processing. There are occasions when host infections cause passage of pathogens in urine. The 3 principal infections leading to significant appearance of pathogens in urine are: urinary schistosomiasis, typhoid fever, and leptospirosis. Coliform and other bacteria may be numerous in urine during urinary tract infections. Since the incidence of these diseases in the U.S. is very low, they constitute little public health risk in water reuse. Microbial agents resulting from venereal infections can also be present in urine, but they are so vulnerable to conditions outside the body that wastewater is not a predominant vehicle of transmission (Feachem *et al*., 1983 and Riggs, 1989).

3.4.1.2 Pathogenic Microorganisms and Health Risks

The potential transmission of infectious disease by pathogenic agents is the most common concern associated with reuse of treated municipal wastewater. Fortunately, sanitary engineering and preventive medical practices have combined to reach a point where waterborne disease outbreaks of epidemic proportions have, to a great extent, been controlled. However, the potential for disease transmission through water has not been eliminated. With few exceptions, the disease organisms of epidemic history are still present in today's sewage. The level of treatment today is more related to severing the transmission chain than to fully eradicating the disease agents.

Many infectious disease microbes affecting individuals in a community can find their way into municipal sewage. Most of the organisms found in untreated wastewater are known as enteric organisms; they inhabit the intestinal tract where they can cause disease, such as diarrhea. **Table 3-2** lists many of the infectious agents potentially present in raw domestic wastewater. These microbes can be classified into 3 broad groups: bacteria, parasites (parasitic protozoa and helminths), and viruses. Table 3-2 also lists the diseases associated with each organism.

a. Bacteria

Bacteria are microscopic organisms ranging from approximately 0.2 to 10 μm in length. They are distributed ubiquitously in nature and have a wide variety of nutritional requirements. Many types of harmless bacteria colonize in the human intestinal tract and are routinely shed in the feces. Pathogenic bacteria are also present in the feces of infected individuals. Therefore, municipal wastewater can contain a wide variety and concentration range of bacteria, including those pathogenic to humans. The numbers and types of these agents are a function of their prevalence in the animal and human community from which the wastewater is derived. Three of the more common bacterial pathogens found in raw wastewater are *Salmonella* sp, *Shigella* sp. and enteropathogenic *Escherichia coli* which have caused drinking water outbreaks with significant numbers of cases of hemolytic uremic syndrome (HUS) and multiple deaths (e.g. Walkerton, Ontario; Washington County, NY; Cabool, MO; Alpine, WY).

Bacterial levels in wastewater can be significantly lowered through either a "removal" or an "inactivation" process. The removal process involves the physical separation of the bacteria from the wastewater through sedimentation and/or filtration. Due to density considerations, bacteria do not settle as individual cells or even colonies. Typically, bacteria can adsorb to particulate matter or floc particles. These particles settle during sedimentation, secondary clarification, or during an advanced treatment process such as coagulation/flocculation/sedimentation using a coagulant. Bacteria can also be removed by using a filtration process that includes sand filters, disk (cloth) filters, or membrane processes. Filtration efficiency for a sand or cloth filter is dependent upon the effective pore size of the filtering medium and the presence of a "pre-coat" layer, usually other particulate matter. Because the pore sizes inherent to microfiltration and ultrafiltration membranes (including those membranes used in membrane bioreactors), bacteria are, to a large extent, completely removed due to size exclusion. Ultimately, the sedimented or filtered bacteria are removed from the overall treatment system through the sludge and backwash treatment system.

Table 3-2. Infectious Agents Potentially Present in Untreated Domestic Wastewater

Pathogen	Disease
Bacteria	
Shigella (spp.)	Shigellosis (bacillary dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes spp.)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis and septicemia, hemolytic uremic syndrome (HUS)
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Campylobacter jejune	Gastroenteritis, reactive arthritis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis (gastroenteritis)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Microsporidia	Diarrhea
Helminths	
Ascaris lumbricoides	Ascariasis (roundworm infection)
Ancylostoma (spp)	Ancylostomiasis (hookworm infection)
Necator americanus	Necatoriasis (roundworm infection)
Ancylostoma (spp.)	Cutaneous larva migrams (hookworm infection)
Strongloides stercoralis	Strongyloidiasis (threadworm infection)
Trichuris trichiura	Trichuriasis (whipworm infection)
Taenia (spp.)	Taeniasis (tapeworm infection)
Enterobius vermicularis	Enterobiasis (pinwork infection)
Echinococcus granulosus (spp.)	Hydatidosis (tapeworm infection)
Viruses	
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A and E virus	Infectious hepatitis
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)
Rotavirus	Gastroenteritis
Parvovirus	Gastroenteritis
Noroviruses	Diarrhea, vomiting, fever
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Coronavirus	Gastroenteritis

Source: Adapted from National Research Council, 1996; Sagik *et. al*., 1978; and Hurst *et. al.,* 1989

Inactivation of bacteria refers to the destruction (death) of bacteria cells or the interference with reproductive ability using a chemical or energy agent. Such inactivation is usually referred to as disinfection. The most common disinfectants used in wastewater treatment are free chlorine, chloramines, ultraviolet (UV) light, and ozone. Chlorine, a powerful chemical oxidant, generally inactivates bacterial cells by causing physiological damage to cell membranes and damage to the internal cell components. Chloramines, chlorine substituted ammonia compounds, generally inactivate bacteria cells by disrupting DNA, thus causing direct cell death and/or inhibiting ability to reproduce. UV light also inactivates bacteria by damaging the DNA, thus inhibiting the ability to reproduce. Ozone, another powerful oxidant, can cause cell inactivation by direct damage to the cell wall and membrane, disruption of enzymatic reaction, and damage to DNA. The relative effectiveness of each chemical disinfectant is generally related to the product of disinfectant concentration and the disinfectant contact time. This product is commonly referenced as the “Ct” value. Tables of various Ct values required to inactivate bacteria (and other pathogens, such as viruses and protozoans) are readily available in the literature for clean (filtered) water applications. These Ct values are a function of temperature, pH, and the desired level of inactivation.

In recognition of the many constraints associated with analyzing wastewater for all of the potential pathogens that may be present, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water. Some bacteria of the coliform group have long been considered the prime indicators of fecal contamination and are the most frequently applied indicators used by state regulatory agencies to monitor water quality. The coliform group is composed of a number of bacteria that have common metabolic attributes. The total coliform groups are all gram-negative aspogenous rods, and most are found in feces of warm-blooded animals and in soil. Fecal coliforms are, for the most part, bacteria restricted to the intestinal tract of warm-blooded animals and comprise a portion of the total coliform group. Coliform organisms are used as indicators because they occur naturally in the feces of warm-blooded animals in higher concentrations than pathogens, are easily detectable, exhibit a positive correlation with fecal contamination, and generally respond similarly to environmental conditions and treatment processes as many bacterial pathogens. Where low levels of coliform organisms are used to indicate the absence of pathogenic bacteria, there is consensus among microbiologists that the total coliform analysis is not superior to the fecal coliform analysis. Specific methods have been developed to detect and enumerate *Escherichia coli* for use as a potential indicator organism.

b. Parasitic Protozoa and Helminths

The most common parasites in domestic untreated wastewater include several genera in the microspora, protozoa, trematode, and nematode families. Since the parasites cannot multiply in the environment, they require a host to reproduce and are excreted in the feces as spores, cysts, oocysts, or eggs, which are robust and resistant to environmental stresses such as dessication, heat, and sunlight. Most parasite spores, cysts, oocysts, and eggs are larger than bacteria and range in size from 1 µm to over 60 µm. While these parasites can be present in the feces of infected individuals who exhibit disease symptoms, carriers with unapparent infections can also excrete them, as may be the case with bacteria and viral infections as well. Furthermore, some protozoa such as *Toxoplasma* and *Cryptosporidium* are among the most common opportunistic infections in patients with acquired immunodeficiency syndrome (AIDS) (Slifko *et al.,* 2000). There are several helminthic parasites that occur in wastewater. Examples include the roundworm *Ascaris* as well as other nematodes such as the hookworms and pinworm. Many of the helminths have complex life cycles, including a required stage in intermediate hosts. The infective stage of some helminths is either the adult organism or larvae, while the eggs or ova of other helminths constitute the infective stage of the organisms. The eggs and larvae, which range in size from about 10 µm to more than 100 µm, are resistant to environmental stresses and may survive usual wastewater disinfection procedures. Helminth ova are readily removed by commonly used wastewater treatment processes such as sedimentation, filtration, or stabilization ponds. A 1992 study in St. Petersburg, Florida, showed helminths were completely removed in the secondary clarifiers (Rose and Carnahan, 1992).

In recent years, the protozoan parasites have emerged as a significant human health threat in regards to chlorinated drinking water. In particular, the protozoa such as *Giardia lamblia*, *Cryptosporidium pavum*, and *Cyclospora cayetanensis* have caused numerous waterborne and/or foodborne outbreaks. *Microsporidia* spp. have also been implicated as a waterborne pathogen (Cotte *et al.,* 1999).

Protozoan pathogens can be reduced in wastewater by the same previously described mechanisms of removal and inactivation. *Cryptosporidium* oocysts are 4 to 6 mm in diameter while *Giardia* cysts range between 8 to 16 mm in diameter. Due to the relatively large size compared to bacteria, the protozoa can be removed by properly designed and operated sedimentation and filtration systems commonly employed in wastewater and water treatment. In terms of inactivation, commonly used disinfectants such as chlorine are not as effective for inactivating the protozoa as compared to bacteria and viruses. **Table 3-3** shows the relative microbial resistance to disinfection compared to *E. coli.* For the chemical disinfectants, a higher Ct value is required to show an equal level of inactivation as compared to bacteria. Advanced disinfection using irradiation such as UV or electron beam treatments have been shown to be effective for inactivating the pathogens with the necessary fluence or dose being roughly equivalent to that required by some bacteria.

c. Viruses

Viruses are obligate intracellular parasites able to multiply only within a host cell and are host-specific. Viruses occur in various shapes and range in size from 0.01 to 0.3 µm in cross-section and are composed of a nucleic acid core surrounded by an outer coat of protein. Bacteriophage are viruses that infect bacteria as the host; they have not been implicated in human infections and are often used as indicators in seeded virus studies. Coliphages are host specific viruses that infect the coliform bacteria.

Enteric viruses multiply in the intestinal tract and are released in the fecal matter of infected persons. Not all types of enteric viruses have been determined to cause waterborne disease, but over 100 different enteric viruses are capable of producing infections or disease. In general, viruses are more resistant to environmental stresses than many of the bacteria, although some viruses persist for only a short time in wastewater. The Enteroviruses, Rotavirus, and the Enteric Adenoviruses, which are known to cause respiratory illness, gastroenteritis, and eye infections, have been isolated from wastewater. Of the viruses that cause diarrheal disease, only the Noroviruss and Rotavirus have been shown to be major waterborne pathogens (Rose, 1986) capable of causing large outbreaks of disease.

There is no evidence that the Human Immunodeficiency Virus (HIV), the pathogen that causes AIDS, can be transmitted via a waterborne route (Riggs, 1989). The results of one laboratory study (Casson *et al*., 1992), where primary and undisinfected secondary effluent samples were inoculated with HIV (Strain IIIB) and held for up to 48 hours at 25° C (77° F), indicated that HIV survival was significantly less than Polio virus survival under similar conditions. A similar study by Casson *et al*. in 1997 indicated that untreated wastewater spiked with blood cells infected with the HIV exhibited a rapid loss of HIV, although a small fraction remained stable for 48 hours.

Similar to bacteria and protozoan parasites, viruses can be both physically removed from the wastewater or inactivated. However, due to the relatively small size of typical viruses, the sedimentation and filtration processes are less effective at removal. Significant virus removal can be achieved with ultrafiltration membranes, possibly in the 3- to 4-log range. However, for viruses, inactivation is generally considered the more important of the 2 main reduction methods. Due to the size and relatively noncomplex nature of viruses, most disinfectants demonstrate reasonable inactivation levels at relatively low Ct values. Interestingly, for UV light disinfection, relatively high fluence values are required to inactivate viruses when compared to bacteria and protozoans. It is believed that the protein coat of the virus shields the ribonucleic acid (RNA) from UV light.

3.4.1.3 Presence and Survival of Pathogens

a. Presence

Bacteria, viruses, and parasites can all be detected in wastewater. Studies of pathogens have reported average levels of 6.2, 5.8, and 5.3 log cfu/100ml of *Yersinia, Shigella,* and *Salmonella* detected in primary-clarified sewage influent over a 2-year period in a U.S. facility (Hench *et al.,* 2003). *Salmonella* may be present in concentrations up to 10,000/l. The excretion of *Salmonella typhi* by asymptomatic carriers may vary from 5 x 10^3 to 45 x 10^6 bacteria/g of feces. But there are few studies in recent years, which have directly investigated the presence of bacterial pathogens and have focused more often on the indicator bacteria. Concentrations excreted by infected individuals range from 10^6 cysts, 10^7 oocysts and as high as 10^{12} virus particle per gram of feces for *Giardia*, *Cryptosporidium,* and *Rotavirus*, respectively (Gerba, 2000). Pathogen levels in wastewater can vary depending on infection in the community.

Levels of viruses, parasites, and indicator bacteria reported in untreated and secondary treated effluents are shown in **Tables 3-4** and **3-5**. These tables illustrate the tremendous range in the concentrations of microorgan-

Table 3-3. **Ct Requirements for Free Chlorine and Chlorine Dioxide to Achieve 99 Percent Inactivation of *E. Coli* Compared to Other Microorganisms**

Microbe	Cl_2 Ct	% Greater Cl_2 Ct Requirement Compared to *E. Coli*	Chloramine Ct	% Greater Chloramine Ct Requirement Compared to *E. Coli*
E. Coli	0.6	NA	113	NA
Poliovirus	1.7	96%	1,420	170%
Giardia	54-250	196-199%	430-580	117-135%
Cryptosporidium	>7,200	>200%	>7,200	>194%

Adapted from: Maier, 2000

isms that may be found in raw and secondary wastewater.

The methods currently used to detect *Cryptosporidium* oocysts and *Giardia* cysts are limited since they cannot assess viability or potential infectivity. Therefore, the health risks associated with finding oocysts and cysts in the environment cannot be accurately ascertained from occurrence data and the risks remain unknown.

Dowd *et al.* (1998) described a polymerase chain reaction (PCR) method to detect and identify the microsporidia (amplifying the small subunit ribosomal DNA of microsporidia). They found isolates in sewage, surface waters, and ground waters. The strain that was most often detected was *Enterocytozoon bieneusi*, which is a cause of diarrhea and excreted from infected individuals into wastewater. Microsporidia spores have been shown to be stable in the environment and remain infective for days to weeks outside their hosts (Shadduck, 1989; Waller, 1980; Shadduck and Polley, 1978). Because of their small size (1 to 5 µm), they may be difficult to remove using conventional filtration techniques. However, initial studies using cell culture suggest that the spores may be more susceptible to disinfection (Wolk *et al.,* 2000).

Under experimental conditions, absorption of viruses and *E. coli* through plant roots, and subsequent acropetal translocation has been reported (Murphy and Syverton, 1958). For example, one study inoculated soil with Polio virus, and found that the viruses were detected in the leaves of plants only when the plant roots were damaged or cut. The likelihood of translocation of pathogens through trees or vines to the edible portions of crops is extremely low, and the health risks are negligible.

Table 3-4. Microorganism Concentrations in Raw Wastewater

Organism	Range in Average Concentrations (CFU, PFU or Cysts/Oocysts)
Fecal Coliforms/100L	105 to 105
Enterococi/100L	10^4 to 10^5
Shigella /100mL	1 to 10^3
Salmonella /100mL	10^2 to 10^4
Helminth ova/100mL	1 to 10^3
Enteric virus/100L	1 to 5 x10^3
Giardia cysts/100L	0.39 to 4.9x10^4
Cryptosporidium oocysts/100L	0.2 to 1.5 x10^3

Source: NRC, 1998 and Maier *et. al*., 2000

Table 3-5. Microorganism Concentrations in Secondary Non-Disinfected Wastewater

Organism	Average Concentrations (CFU, PFU, or Cysts/Oocysts per 100L)
Fecal Coliforms	7,764
Enterococci	2,186
Enteric virus	20 to 650
Giardia cysts	5 to 2,297
Cryptosporidium oocysts	140

Source: NRC, 1998

b. Survival

Most pathogens do not increase in numbers outside of their host, although in some instances the ova of helminths do not mature to the larval stage until they are in the soil. In all cases, the numbers decrease at various rates, depending on a number of factors including the inherent biologic nature of the agent, temperature, pH, sunlight, relative humidity, and competing flora and fauna. Examples of relative survival times for some pathogens are given in **Table 3-6**. These values are intended to indicate relative survival rates only, and illustrate the various persistence of selected organisms.

3.4.1.4 Pathogens and Indicator Organisms in Reclaimed Water

There have been a number of studies regarding the presence of pathogens and indicator organisms in reclaimed water and such studies continue as experience in this field expands. Koivunen *et al.* (2003) compared the reduction of fecal coliforms to the reduction of S*almonella* by conventional biological treatment, filtration, and disinfection. Fecal coliform bacteria were present at 1000-fold greater concentration, and the *Salmonella* bacteria were reduced to non-detectable levels by advanced treatment (greater than 99.9 percent). Fecal coliform bacteria were a good, conservative indicator of such reductions. However, given the numbers of *Salmonellae* in secondary effluents and the fact that 18 carried multiple antibiotic resistance, the authors concluded that without proper additional advanced treatment, there may be a significant public health risk.

A year-long study investigated a conventional reuse treatment facility in St. Petersburg, Florida (Rose *et al*., 1996). In this facility, deep-bed sand filtration and disinfection, with total chlorine residual (4 to 5 mg/L) were the barriers assessed through both monitoring of naturally occurring bacteria, protozoa, and viruses, as well as through seeded challenge studies. Removals were 5 log for human vi-

Table 3-6. Typical Pathogen Survival Times at 20-30 °C

Pathogen	Survival Time (days)		
	Fresh Water & Sewage	Crops	Soil
Viruses[a]			
Enteroviruses[b]	<120 but usually <50	<60 but usually <15	<100 but usually <20
Bacteria			
Fecal coliforms[a,c]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Salmonella spp.[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Shigella spp.[a]	<30 but usually <10	<10 but usually <5	---
Vibrio cholerae[d]	<30 but usually <10	<5 but usually <2	<20 but usually <10
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2	<20 but usually <10
Helminths			
Ascaris lumbricoides eggs	Many months	<60 but usually <30	Many months

a In seawater, viral survival is less and bacterial survival is very much less, than in fresh water.
b Includes polio-, echo-, and coxsackieviruses
c Fecal coliform is not a pathogen but is often used as an indicator organism
d *V. cholerae* survival in aqueous environments is a subject of current uncertainty.

Source: Adapted from Feacham *et. al*., 1983

ruses and coliphage indicators, with anywhere from 1.5 to 3 log reductions by disinfection. A 3 log reduction for protozoa was achieved and greater than 1 log reduction was achieved for bacteria and indicators. Protozoan viability was not evaluated. In this study, *Enterococci* and *Clostridium* were not included as alternative indicators. Only the phage was used as a virus indicator. Seeded trials using bacteriophage demonstrated a 1.5 and 1.6 log reduction by filtration and disinfection, respectively.

A second study was done at the Upper Occoquan Sewage Authority (UOSA) in Fairfax County, Virginia. Samples were collected once per month for 1 year from 8 sites from the advanced wastewater reclamation plant (Rose *et al.,* 2000). The 8 sites were monitored for indicator bacteria, total and fecal coliforms, enterococci, *Clostridium,* coliphage (viruses which infect *E.coli*), human enteric viruses, and enteric protozoa. Multimedia filtration reduced the bacteria by approximately 90 percent, but did not effectively reduce the coliphage or enteroviruses. The enteric protozoa were reduced by 85 to 95.7 percent. Chemical lime treatment was the most efficient barrier to the passage of microorganisms (reducing these microorganisms by approximately 99.99 percent for bacteria, 99.9 percent for *Clostridium* and enteroviruses, and 99 percent for protozoa). Disinfection was achieved through chlorination (free chlorine residuals of 0.2 to 0.5 mg/l), and effectively achieved another 90 to 99 percent reduction. Overall, the plant was able to achieve a 5 to 7 log reduction of bacteria, 5 log reduction of enteroviruses, 4 log reduction of *Clostridium*, and 3.5 log reduction of protozoa. Total coliforms, enterococci, *Clostridium*, coliphage, *Cryptosporidium,* and *Giardia* were detected in 4 or fewer samples of the final effluent. No enteroviruses or fecal coliforms were detected. Protozoa appeared to remain the most resistant microorganisms found in wastewater. However, as with the St. Petersburg study, protozoan viability in these studies was not addressed.

Table 3-7 provides a summary of influent and effluent microbiological quality for the St. Petersburg and Upper Occaquan studies for enterovirus, *Cryptosporidium,* and *Giardia*. Enteroviruses were found 100 percent of the time in untreated wastewater. The enteric protozoa, *Cryptosporidium,* and *Giardia* were found from 67 to 100 percent of the time in untreated wastewater. *Giardia* cysts were found to be more prevalent, and at higher concentrations than oocysts in wastewater, perhaps due to the increased incidence of infection in populations compared to cryptosporidiosis and higher asymptomatic infections. Levels of oocysts in sewage are similar throughout the world (Smith and Rose, 1998). However, crops irrigated with wastewater of a poorer quality in

Table 3-7 Pathogens in Untreated and Treated Wastewater

City	Organism	Untreated Wastewater		Reclaimed Water	
		% Positive	Average Value	% Positive	Average Value
St. Petersburg, FL	Enterovirus (PFU/100l)	100	1,033	8	0.01
	Cryptosporidium (oocysts/100l)	67	1,456	17	0.75
	Giardia (cysts/100l)	100	6,890	25	0.49
Upper Occoquan, VA	Enterovirus (PFU/100l)	100	1,100	0	0
	Cryptosporidium (oocysts/100l)	100	1,500	8.3	0.037
	Giardia (cysts/100l)	100	49,000	17	1.1

Source: Walker-Coleman *et. al.,* 2002; Rose and Carnahan, 1992; Sheikh and Cooper, 1998; Rose *et. al.,* 2001; Rose and Quintero-Betancourt, 2002; and York *et. al.,* 2002

Israel contained more oocysts than cysts (Armon *et al.,* 2002).

The results of these studies indicate that the treatment processes employed are capable of significantly reducing or eliminating these pathogens.

The State of Florida recognizes that *Giardia* and *Cryptosporidium* are pathogens of increasing importance to water reclamation and now requires monitoring for these pathogens (Florida DEP, 1999). Results of this monitoring are presented in **Table 3-8**. The Florida facilities highlighted in this table generally feature secondary treatment, filtration, and high-level disinfection. **Table 3-9** includes the associated data from these facilities for TSS, turbidity, and total chlorine residual.

Visual inspection studies in Florida and elsewhere routinely found *Giardia* cysts and *Cryptosporidium* oocysts in reclaimed water that received filtration and high-level disinfection and was deemed suitable for public access uses. A number of more detailed studies which considered the viability and infectivity of the cysts and oocysts suggested that *Giardia* was likely inactivated by chlorine but 15 to 40 percent of detected *Cryptosporidium* oocysts may survive (Keller, 2002; Sheikh, 1999; Garcia, 2002; Genacarro, 2003; Quintero, 2003). Other studies evaluating UV and the electron beam as alternatives to chlorine disinfection found that both parasites were easily inactivated (Mofidi 2002 and Slifko 2001). Both *Giardia* cysts and *Cryptosporidium* oocysts required less than 10mJ/cm^2 for complete inactivation by UV (Mofidi 2002 and Slifko 2001).

In December 2003, the Water Environment Research Foundation (WERF) initiated a series of workshops on indicators for pathogens in wastewater, stormwater, and biosolids. The first workshop considered the state of science for indicator organisms. Potential indicators for further study were identified in an attempt to improve upon current indicator organism use and requirements. The results of this effort are summarized in **Table 3-10**. Subsequent phases of this effort will evaluate the usefulness of the selected list of indicators and compare them with current indicators. Detailed studies will then be conducted using the most promising indicators in field studies at various sites in the U.S.

3.4.1.5 Aerosols

Aerosols are defined as particles less than 50 µm in diameter that are suspended in air. Viruses and most pathogenic bacteria are in the respirable size range; hence, the inhalation of aerosols is a possible direct mean of human infection. Aerosols are most often a concern where reclaimed water is applied to urban or agricultural sites with sprinkler irrigation systems, or where it is used for cooling water make-up.

The concentration of pathogens in aerosols is a function of their concentration in the applied water and the aerosolization efficiency of the spray process. During spray irrigation, the amount of water that is aerosolized can vary from less than 0.1 percent to almost 2 percent, with a mean aerosolization efficiency of 1 percent or less. Infection or disease may be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of some pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract. Therefore, for some pathogens, inhalation may be a more likely route for disease transmission than either contact or ingestion.

The infectivity of an inhaled aerosol depends on the depth of the respiratory penetration and the presence of pathogenic organisms capable of infecting the respiratory sys-

Table 3-8. Summary of Florida Pathogen Monitoring Data

Statistic	*Giardia*	*Cryptosporidium*
Number of observations	69	68
% having detectable concentrations	58%	22%
25 percentile (#/100 l)	ND	ND
50 percentile (#/100 l)	4	ND
75 percentile (#/100 l)	76	ND
90 percentile (#/100 l)	333	2.3
Maximum (#/100 l)	3,096	282

Notes: (a) All numeric data are total numbers of cysts or oocysts per 100 L.
(b) ND indicates a value less than detection.
Source: Walker-Coleman, *et. al.,* 2002.

Table 3-9. Operational Data for Florida Facilities

Statistic	TSS (mg/l)	Turbidity (NTU)	Chlorine Residual (mg/l)
Minimum	0.19	0.31	1.01
10 percentile	0.4	0.45	1.9
25 percentile	0.8	0.65	2.32
50 percentile	1	0.99	4.1
75 percentile	1.76	1.36	5
90 percentile	2.1	1.8	7.1
Maximum	6	4.5	10.67

Source: Walker-Coleman *et. al.,* 2002

tem. Aerosols in the 2 to 5 µm size range are generally excluded from the respiratory tract, with some that are subsequently swallowed. Thus, if gastrointestinal pathogens are present, infection could result. A considerably greater potential for infection occurs when respiratory pathogens are inhaled in aerosols smaller than 2 µm in size, which pass directly to the alveoli of the lungs (Sorber and Guter, 1975).

One of the most comprehensive aerosol studies, the Lubbock Infection Surveillance Study (Camann *et al*., 1986), monitored viral and bacterial infections in a mostly rural community surrounding a spray injection site near Wilson, Texas. The source of the irrigation water was undisinfected trickling filter effluent from the Lubbock Southeast water reclamation plant. Spray irrigation of the wastewater significantly elevated air densities of fecal coliforms, fecal streptococci, mycobacteria, and coliphage above the ambient background levels for at least 650 feet (200 meters) downwind. The geometric mean concentration of enteroviruses recovered 150 to 200 feet (44 to 60 meters) downwind was 0.05 pfu/m^3, a level higher than that observed at other wastewater aerosol sites in the U.S. and in Israel (Camann *et al*., 1988). While disease surveillance found no obvious connection between the self-reporting of acute illness and the degree of aerosol exposure, serological testing of blood samples indicated that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure (Camann *et al*., 1986).

For intermittent spraying of disinfected reclaimed water, occasional inadvertent contact should pose little health hazard from inhalation. Cooling towers issue aerosols continuously, and may present a greater concern if the water is not properly disinfected. Although a great deal of effort has been expended to quantify the numbers of fecal coliforms and enteric pathogens in cooling tower waters, there is no evidence that they occur in large num-

Table 3-10 Some Suggested Alternative Indicators for Use in Monitoring Programs

Parameter	Pathogen Presence
Viruses	F+ RNA coliphages
	Somatic coliphages
	Adenovirus
	JC virus
Bacteria	*E. coli*
	Enterococci
	Bifidobacteria
Parasites	*Clostridium perfringens*
	Sulfite reducing
	Clostridium spp.
Non-microbial indicators	Fecal sterols
Pathogens as possible indicators	*Cryptosporidium*
	Giardia

Source: WERF Workshop, 2003

bers, although the numbers of other bacteria may be quite large (Adams and Lewis, n.d.).

No documented disease outbreaks have resulted from the spray irrigation of disinfected, reclaimed water. Studies indicate that the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (U.S. EPA, 1980b). However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols produced from reclaimed water that is not highly disinfected. Exposure is limited through design or operational controls. Design features include:

- Setback distances, which are sometimes called buffer zones
- Windbreaks, such as trees or walls around irrigated areas
- Low pressure irrigation systems and/or spray nozzles with large orifices to reduce the formation of fine mist
- Low-profile sprinklers
- Surface or subsurface methods of irrigation

Operational measures include:

- Spraying only during periods of low wind velocity
- Not spraying when wind is blowing toward sensitive areas subject to aerosol drift or windblown spray
- Irrigating at off-hours, when the public or employees would not be in areas subject to aerosols or spray

All these steps would be considered part of a best management plan for irrigation systems regardless of the source of water used.

Most states with reuse regulations or guidelines include setback distances from spray areas to property lines, buildings, and public access areas. Although predictive models have been developed to estimate microorganism concentrations in aerosols or larger water droplets resulting from spray irrigation, setback distances are determined by regulatory agencies in a somewhat arbitrary manner, using levels of disinfection, experience, and engineering judgment as the basis.

3.4.1.6 Infectious Disease Incidence Related to Wastewater Reuse

Epidemiological investigations have focused on wastewater-contaminated drinking water supplies, the use of raw or minimally-treated wastewater for food crop irrigation, health effects to farm workers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater. These investigations have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem *et al*., 1983; Shuval *et al*., 1986).

Review of the scientific literature, excluding the use of raw sewage or primary effluent on sewage farms in the late 19th century, does not indicate that there have been no confirmed cases of infectious disease resulting from reclaimed water use in the U.S. where such use has been in compliance with all appropriate regulatory controls. However, in developing countries, the irrigation of market crops with poorly treated wastewater is a major source of enteric disease (Shuval *et al.*, 1986).

Occurrences of low level or endemic waterborne diseases associated with exposure to reclaimed water have been difficult to ascertain for several reasons:

- Current detection methods have not been sufficiently sensitive or specific enough to accurately detect low concentrations of pathogens, such as viruses and protozoa, even in large volumes of water.
- Many infections are often not apparent, or go unreported, thus making it difficult to establish the endemicity of such infections.
- The apparently mild nature of many infections preclude reporting by the patient or the physician.
- Current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of these diseases through water.
- Illness due to enteroviral or parasite infections may not become obvious for several months or years.
- Once introduced into a population, person-to-person contact can become a secondary mode of transmission of many pathogens, thereby obscuring the role of water in its transmission.

Because of the insensitivity of epidemiological studies to provide a direct empirical assessment of microbial health risk due to low-level exposure to pathogens, methodologies have increasingly relied on indirect measures of risk by using analytical models for estimation of the intensity of human exposure and the probability of human response from the exposure. Microbial risk assessment involves evaluating the likelihood that an adverse health effect may occur from human exposure to one or more potential pathogens. Most microbial risk assessments in the past have used a framework originally developed for chemicals that is defined by 4 major steps: (1) hazard identification, (2) dose-response identification, (3) exposure assessment, and (4) risk characterization. However, this framework does not explicitly acknowledge the differences between health effects due to chemical exposure versus those due to microbial exposure. Those differences include acute versus chronic health effects, potential for person-to-person transmission of disease, and the potential need to account for the epidemiological status of the population (Olivieri, 2002).

Microbial risk analyses require several assumptions to be made. These assumptions include a minimum infective dose of selected pathogens, concentration of pathogens present, quantity of pathogens ingested, inhaled, or otherwise contacted by humans, and probability of infection based on infectivity models. The use of microbial risk assessment models have been used extensively by the U.S. Department of Agriculture (USDA) to evaluate food safety for pathogens such as Listeria Monocytogenes in ready to eat foods (USDA, n.d.). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) also provide risk assessment methodologies for use in evaluating food safety (Codex Alimentarius).

In order to assess health risks associated with the use of reclaimed water, pathogen risk assessment models to assess health risks associated with the use of reclaimed water have been used as a tool in assessing relative health risks from microorganisms in drinking water (Cooper *et al.,* 1986; Gerba and Haas, 1988; Olivieri *et al.,* 1986; Regli *et al*., 1991; Rose *et al*., 1991; Gale, 2002) and reclaimed water (Asano and Sakaji, 1990; EOA, Inc., 1995; Rose and Gerba, 1991; Tanaka *et al*., 1998; Patterson *et al*., 2001). Most of the models calculated the probability of individual infection or disease as a result of a single exposure. One of the more sophisticated models calculates a distribution of risk over the population by utilizing epidemiological data such as incubation period, immune status, duration of disease, rate of symptomatic development, and exposure data such as processes affecting pathogen concentration (EOA, Inc., 1995).

At the present time, no wastewater disinfection or reclaimed water standards or guidelines in the U.S. are based on risk assessment using microorganism infectivity models. Florida is investigating such an approach and has suggested levels of viruses between 0.04 to 14/100 l, depending on the virus (ranging from Rotavirus infectivity to a less infectious virus), viable oocysts at 22/100 l, and viable cysts at 5/100 l (York and Walker-Coleman, 1999). Microbial risk assessment methodology is a useful tool in assessing relative health risks associated with water reuse. Risk assessment will undoubtedly play a role in future criteria development as epidemiological-based models are improved and refined.

3.4.1.7 Chemical Constituents

The chemical constituents potentially present in municipal wastewater are a major concern when reclaimed water is used for potable reuse. These constituents may also affect the acceptability of reclaimed water for other uses, such as food crop irrigation or aquaculture. Potential mechanisms of food crop contamination include:

- Physical contamination, where evaporation and repeated applications may result in a buildup of contaminants on crops
- Uptake through the roots from the applied water or the soil, although available data indicate that potentially toxic organic pollutants do not enter edible portions of plants that are irrigated with treated municipal wastewater (National Research Council, 1996)
- Foliar uptake

With the exception of the possible inhalation of volatile organic compounds (VOCs) from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed. Chemical constituents are a consideration when reclaimed water percolates into groundwater as a result of irrigation, groundwater recharge, or other uses. These practices are covered in Chapter 2. Some of the inorganic and organic constituents in reclaimed water are listed in **Table 3-11**.

a. Inorganics

In general, the health hazards associated with the ingestion of inorganic constituents, either directly or through food, are well established (U.S. EPA, 1976). EPA has set maximum contaminant levels (MCLs) for drinking water. The concentrations of inorganic constituents in reclaimed water depend mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/l of dissolved inorganic solids, although the amount added can range from approximately 150 mg/l to more than 500 mg/l (Metcalf & Eddy, 2002). As indicated in Table 3-11 the presence of total dissolved solids, nitrogen, phosphorus, heavy metals, and other inorganic constituents may affect the acceptability of reclaimed water for different reuse applications. Wastewater treatment using existing technology can generally reduce many trace elements to below recommended maximum levels for irrigation and drinking water. Uses in wetlands and recreational surface waters must also consider aquatic life protection and wetland habitat.

b. Organics

The organic make-up of raw wastewater includes naturally occurring humic substances, fecal matter, kitchen wastes, liquid detergents, oils, grease, and other substances that, in one way or another, become part of the sewage stream. Industrial and residential wastes may contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the end use of reclaimed water. Some of the adverse effects associated with organic substances include:

- Aesthetic effects – organics may be malodorous and impart color to the water
- Clogging – particulate matter may clog sprinkler heads or accumulate in soil and affect permeability
- Proliferation of microorganisms – organics provide food for microorganisms
- Oxygen consumption – upon decomposition, organic substances deplete the dissolved oxygen content in streams and lakes. This negatively impacts the aquatic life that depends on the oxygen supply for survival
- Use limitation – many industrial applications cannot tolerate water that is high in organic content
- Disinfection effects – organic matter can interfere with chlorine, ozone, and ultraviolet disinfection, thereby making them less available for disinfection purposes. Further, chlorination may result in formation of potentially harmful disinfection byproducts
- Health effects – ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The wide range of anthropogenic organic contaminants in streams influenced by urbanization (including wastewater contamination) includes pharmaceuticals, hormones, antioxidants, plasticizers, solvents, polynuclear aromatic hydrocarbons (PAHs), detergents, pesticides, and their metabolites (Kolpin *et al.,* 2002). The stability and persistence of these compounds are extremely variable in the stream/sediment environment. A recent comprehensive study of the persistence of anthropogenic and natural organic molecules during groundwater recharge suggests that carbamezepine may survive long enough to serve as a useful tracer compound of wastewater origin (Clara *et al.,* 2004).

Table 3-11. Inorganic and Organic Constituents of Concern in Water Reclamation and Reuse

Constituent	Measured Parameters	Reasons for Concern
Suspended Solids	Suspended solids (SS), including volatile and fixed solids	Organic contaminants, heavy metals, etc. are absorbed on particulates. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable Organics	Biochemical oxygen demand, chemical oxygen demand, total organic carbon	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is u
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesir
Stable Organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses. Chlorine reacts with man
Hydrogen Ion Concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy Metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the reclaimed water for irrigation or other uses.
Dissolved Inorganics	Total dissolved solids, electrical Conductivity, specific elements (e.g., Na, Ca, Mg, Cl, and B)	Excessive salinity may damage some crops. Specific inorganics electrical conductivity ions such as chloride, sodium, and boron are toxic to specific elements (e.g., in some crops, sodium may pose soil permeability Na, Ca, Mg, Cl, and B problems).
Residual Chlorine	Free and combined chlorine	Excessive amounts of free available chlorine (>0.05 Chlorine chlorine mg/l) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combined form, which does not cause crop damage. Some concerns are expre

Source: Adapted from Pettygrove and Asano, 1985

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse. In addition, these constituents may be of concern where reclaimed water is utilized for food crop irrigation, where reclaimed water from irrigation or other beneficial uses reaches potable groundwater supplies, or where the organics may bioaccumulate in the food chain (e.g., in fish-rearing ponds).

Traditional measures of organic matter such as BOD, chemical oxygen demand (COD), and total organic carbon (TOC), are widely used as indicators of treatment efficiency and water quality for many nonpotable uses of reclaimed water. However, these measures have only indirect relevance related to evaluating toxicity and health effects. Sophisticated analytical instrumentation makes it possible to identify and quantify extremely low levels of organic constituents in water. Examples include gas chromatography/tandem mass spectrometry (GC/MS/MS) or high performance liquid chromatography/mass spectrometry (HPLC/MS). These analyses are costly and may require extensive and difficult sample preparation, particularly for nonvolatile organics.

Organic compounds in wastewater can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. In the past, most attention was focused on the trihalomethane (THM) compounds; a family of organic compounds typically occurring as chlorine or bromine-substituted forms of methane. Chloroform, a commonly found THM compound, has been implicated in the development of cancer of the liver and kidney. Improved analytical capabilities to detect extremely low levels of chemical constituents in water have resulted in identification of several health-significant chemicals and disinfection byproducts in recent years. For example, the extremely potent carcinogen, N-nitrosodimethylamine (NDMA) is present in sewage and is produced when municipal wastewater effluent is disinfected with chlorine or chloramines (Mitch *et al*, 2003). In some situations, the concentration of NDMA present in reclaimed water exceeds action levels set for the protection of human health, even after reverse osmosis treatment. To address concerns associated with NDMA and other trace organics in reclaimed water, several utilities in California have installed UV/H2O2 treatment systems for treatment of reverse osmosis permeate.

Quality standards have been established for many inorganic constituents. Treatment and analytical technology has demonstrated the capability to identify, quantify, and control these substances. Similarly, available technology is capable of eliminating pathogenic agents from contaminated waters. On the basis of available information, there is no indication that health risks from using highly treated reclaimed water for potable purposes are greater than those from using existing water supplies (National Research Council, 1994). Yet, unanswered questions remain about organic constituents, due mainly to their potentially large numbers and unresolved health risk potentials related to long-term, low-level exposure. Assessment of health risks associated with potable reuse is not definitive due to limited chemical and toxicological data and inherent limitations in available epidemiological and toxicological methods. The results of epidemiological studies directed at drinking water have generally been inconclusive, and extrapolation methodologies used in toxicological assessments provide uncertainties in overall risk characterization (National Research Council, 1998).

3.4.1.8 Endocrine Disrupters

In addition to the potential adverse effects of chemicals described in Section 3.4.1.6, certain chemical constituents present in wastewater also can disrupt hormonal systems. This phenomenon, which is referred to as endocrine disruption, can occur through a variety of mechanisms associated with hormone synthesis, hormone receptor binding, and hormone transformation. As a result of the many mechanisms through which chemicals can impact hormone function, a large number of chemicals are classified as endocrine disrupters. However, the exact types of chemicals that are classified as endocrine disrupters vary among researchers. **Table 3-12** highlights a number of example sources of potential endocrine disrupters.

For example, the oxyanion, perchlorate, is an endocrine disrupter because it affects the thyroid system (U.S. EPA, 2002). The herbicide, atrazine, is an endocrine disrupter because it affects an enzyme responsible for hormone regulation (Hayes *et al.* 2002). A USGS project recently sampled 139 streams in 30 states for any 1 of 95 endocrine disrupters. The results indicated that 80 percent of the streams had at least 1 of these compounds (McGovern and McDonald, 2003). The topic of endocrine disruption has significant implications for a wide variety of chemicals used by industry, agriculture, and consumers. As a result, the EPA, the European Union (EU), and other government organizations are currently evaluating approaches for regulating endocrine-disrupting chemicals.

With respect to water reuse, the greatest concerns associated with endocrine disruption are related to a series of field and laboratory studies demonstrating that chemicals in wastewater effluent caused male fish to exhibit female characteristics (Purdom *et al.,* 1994; Harries *et al.,* 1996; Harries *et al.,* 1997). This process, which is referred to as feminization, has been attributed mostly to the presence of steroid hormones excreted by humans

(Desbrow *et al.,* 1998 and Snyder *et al.,* 2001). The hormones involved in fish feminization include the endogenous (*i.e.,* produced within the body) hormone 17b-estradiol as well as hormones present in pharmaceuticals (*e.g.,* ethinyl estradiol in birth control pills). Other chemicals capable of feminizing fish are also present in wastewater. These include nonylphenol and alkylphenol polyethoxylates, both of which are metabolites of nonionic detergents formed during secondary wastewater treatment (Ahel *et al.,* 1994).

The specific endocrine-disrupting chemicals in reclaimed water can be quantified using modern analytical methods. As indicated previously, the compounds most likely to be responsible for feminization of fish include steroid hormones (*e.g.,* 17b-estradiol and ethinyl estradiol) and detergents metabolites (*e.g.,* nonylphenol and alkylphenol polyethoxylates). Although these compounds cannot be quantified at the levels expected in reclaimed water with the gas chromatography/mass spectrometry (GC/MS) techniques routinely used to quantify priority pollutants, they can be measured with equipment available in many modern laboratories. For the hormones, analytical methods such as gas chromatography/tandem mass spectrometry (GC/MS/MS) (Ternes *et al.,* 1999, Huang and Sedlak, 2001), high performance liquid chromatography/mass spectrometry (HPLC/MS) (Ferguson *et al.,* 2001), or immunoassays (Huang and Sedlak, 2001 and Snyder *et al.,* 2001) are needed to detect the low concentrations present in wastewater effluent (*e.g.,* ethinyl estradiol concentrations are typically less than 2 υg/l in wastewater effluent). Although the endocrine-disrupting detergent metabolites are present at much higher concentrations than the hormones, their analysis also requires specialized analytical methods (Ahel *et al.,* 1994) not available from many commercial laboratories.

Bioassays can also be used to quantify the potential of reclaimed water to cause endocrine disruption. These methods are attractive because they have the potential to detect all of the difficult-to-measure endocrine-disrupting chemicals in 1 assay. The simplest bioassays involve *in vitro* tests, in which a hormone receptor from a mammalian cell is used to detect endocrine-disrupting chemicals. Among the different *in vitro* assays, the Yeast Estrogen Screen (YES) assay has been employed most frequently (Desbrow *et al.,* 1998). Comparisons between *in vitro* bioassays and chemical measurements yield

Table 3-12. Examples of the Types and Sources of Substances that have been Reported as Potential Endocrine-Disrupting Chemicals

Category	Examples of Substances	Examples of Uses	Examples of Sources
Polychlorinated Compounds	polychlorinated dioxins and polychlorinated biphenyls	industrial production of byproducts (mostly banned)	incineration and landfill runoff
Organochlorine Pesticides	DDT, dieldrin, and lindane	insecticides (many phased out)	agricultural runoff
Current Use Pesticides	atrazine, trifluralin, and permethrin	pesticides	agricultural runoff
Organotins	tributyltin	antifoulants on ships	harbors
Alkylphenolics	nonylphenol and octylphenol	surfactants (and their metabolites)	industrial and municipal effluents
Phthalates	dibutyl phthalate and butylbenzyl phthalate	plasticisers	industrial effluent
Sex Hormones	17-beta estradiol and estrone	produced naturally by animals	municipal effluents
Synthetic Steroids	ethinylestradiol	contraceptives	municipal effluents
Phytoestrogens	isoflavones, lignans, coumestans	present in plant material	pulp mill effluents

Source: Adapted from McGovern and McDonald, 2003 and Berkett and Lester, 2003 consistent results, indicating that steroid hormones are the most significant endocrine disrupting chemicals in wastewater effluent. Unfortunately, *in vitro* bioassays do not always detect compounds that disrupt hormone systems through mechanisms other than binding to hormone receptors. As a result, *in vivo* bioassays, usually performed with fish, may provide more accurate results. A clear dose-related response to various endocrine-disrupting compounds has been established in fish; however, little is known about species differences in sensitivity to exposure. Individual responses to exposure may also vary widely (Routledge *et al.*, 1998). Because many laboratories are unable to perform *in vivo* bioassays under the necessary conditions (*e.g.*, flow-through tests with rainbow trout), *in vivo* bioassays are not always practical. Available data suggest that nitrification/denitrification and filtration can reduce the concentrations of hormones and detergent metabolites while reverse osmosis lowers concentrations to levels that are unlikely to cause endocrine disruption (Huang and Sedlak, 2001 and Fujita *et al.,* 1996).

The current focus of research on disruption of the estrogen system may be attributable to the relative ease of detecting this form of endocrine disruption. As additional research is performed, other chemicals in wastewater effluent may be found to disrupt hormonal systems through mechanisms yet to be documented. For example, although results from *in vitro* bioassays suggest that the steroid hormones are most likely responsible for feminization of fish, it is possible that other endocrine disrupters contribute to the effect through mechanisms that cannot be detected by the bioassays.

The ecological implications associated with the feminization of fish are unknown. The potential of reclaimed water to cause endocrine disruption in humans is also unknown. It is anticipated that problems associated with endocrine disruption could occur, given prolonged consumption of substantial volumes of polluted water. The compounds in wastewater effluent that are believed to be responsible for feminization of fish may not pose a serious risk for humans because of differences between human and fish physiology. For example, the hormone 17b-estradiol is not used in the oral form in clinical applications because it would be metabolized before it could reach its target. Nevertheless, the evidence of endocrine disruption in wildlife and the absence of data about the effects of low-level exposure to endocrine disrupting compounds in humans has led to new scrutiny regarding endocrine-disrupting chemicals in reclaimed water.

3.4.2 Treatment Requirements

Untreated municipal wastewater may include contributions from domestic and industrial sources, infiltration and inflow from the collection system, and, in the case of combined sewer systems, urban stormwater runoff. The quantity and quality of wastewater derived from each source will vary among communities, depending on the number and type of commercial and industrial establishments in the area and the condition of the sewer system.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as anything beyond secondary treatment. A generalized flow sheet for municipal wastewater treatment is shown in **Figure 3-10**.

In the last decade, significant advances were made in wastewater treatment equipment, design, and technology. For example, biological nutrient removal (BNR) processes have become more refined. Membranes are capable of producing higher quality effluent at higher flux rates and lower pressures than was possible before. Membrane bioreactors (MBRs) have shown to be effective in producing a high quality effluent, while greatly reducing a treatment plant's footprint. Microfiltration, used in some locations to replace conventional media filtration, has the advantage of effectively removing all parasite cysts (e.g., *Giardia* and *Cryptosporidium*). Advances in UV radiation technology have resulted in a cost competitive disinfection process capable of reducing the concentration of most pathogens to extremely low levels.

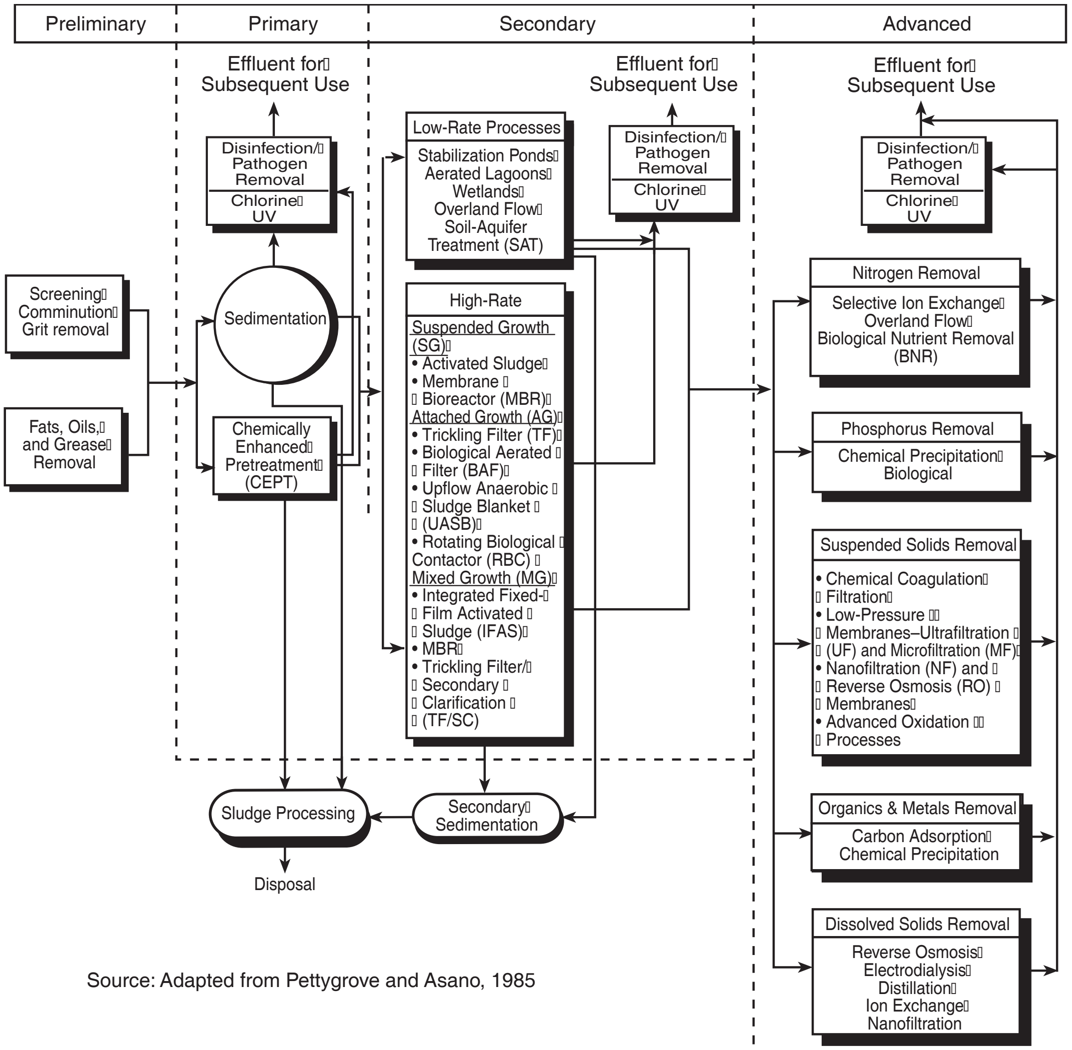
Wastewater treatment from raw to secondary is well understood and covered in great detail in other publications such as the Manual of Practice (MOP) 8, *Design of Municipal Wastewater Treatment Plants*, 4th Edition, (WEF, 1998). In this edition of the *Guidelines for Water Reuse* the discussion about treatment processes will be limited to those with a particular application to water reuse and reclamation. Such processes generally consist of disinfection and treatment beyond secondary treatment, although some limited access reuse programs may use secondary effluent without concern. It should be pointed out that treatment for particular pollutants at the water reclamation facility is not always the best answer. Source controls should also be investigated. In Orange County, California, 1,4-dioxane (listed as a probable human carcinogen based on animal studies) was found in 9 production wells at levels greater than the California action levels. This problem was solved by working with a treatment plant customer who voluntarily ceased discharge of 1,4-dioxane to the sewer system (Woodside and Wehner, 2002).

3.4.2.1 Disinfection

The most important process for the destruction of microorganisms is disinfection. In the U.S., the most common disinfectant for both water and wastewater is chlorine. Ozone and UV light are other prominent disinfectants used at wastewater treatment plants. Factors that should be considered when evaluating disinfection alternatives include disinfection effectiveness and reliability, capital costs, operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects. Examples of adverse effects include toxicity to aquatic life or formation of toxic or carcinogenic substances. The predominant advantages and disadvantages of disinfection alternatives are well known and have been summarized by the EPA in their Wastewater Technology Fact Sheets on Ultraviolet Disinfection (September 1999), Ozone Disinfection (September 1999), and Chlorine Disinfection (September 1999), Design Manual entitled, “Municipal Wastewater Disinfection” and Water Environment Federation (WEF) Manual of Practice FD-10 (1996).

The efficiency of chlorine disinfection depends on the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than viruses, which in turn, are less resistant than parasite ova and cysts.

Figure 3-10. Generalized Flow Sheet for Wastewater Treatment



Source: Adapted from Pettygrove and Asano, 1985

The chlorine dosage required to disinfect wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are:

- Organic constituents, which consume the disinfectant
- Particulate matter, which protects microorganisms from the action of the disinfectant
- Ammonia, which reacts with chlorine to form chloramines, a much less effective disinfectant species than free chlorine

In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

Chlorine is a regulated substance with a threshold quantity of 2,500 pounds (1130 kg). If a chlorine system contains a larger quantity of chlorine than the threshold quantity, a Risk Management Plan (RMP) must be completed. Two main factors of the RMP that prompt many municipalities to switch to alternative disinfection systems are: (1) the RMP is not a one-time requirement, it has to be updated every 5 years; and (2) concern over public reaction to the RMP, which requires that a “kill zone” be geographically defined around the treatment facility. This “kill zone” may include residential areas near the treatment plant. Thus, RMP requirements and decreasing chemical costs for commercial grade sodium hypochlorite have resulted in many municipalities switching from chlorine gas to commercial grade sodium hypochlorite to provide disinfection of their wastewater.

Ozone (O_3), is a powerful disinfecting agent and chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removing color, and contributing dissolved oxygen. Some disadvantages to using ozone for disinfection are: (1) the use of ozone is relatively expensive and energy intensive, (2) ozone systems are more complex to operate and maintain than chlorine systems, and (3) ozone does not maintain a residual in water.

UV is a physical disinfecting agent. Radiation at a wavelength of 254 mm penetrates the cell wall and is absorbed by the cellular nucleic acids. This can prevent replication by eliminating the organism’s ability to cause infection. UV radiation is frequently used for wastewater treatment plants that discharge to surface waters to avoid the need for dechlorination prior to release of the effluent. UV is receiving increasing attention as a means of disinfecting reclaimed water for the following reasons: (1) UV may be less expensive than disinfecting with chlorine, (2) UV is safer to use than chlorine gas, (3) UV does not result in the formation of chlorinated hydrocarbons, and (4) UV is effective against *Cryptosporidium* and *Giardia*, while chlorine is not.

The effectiveness of UV radiation as a disinfectant (where fecal coliform limits are on the order of 200/100 ml) has been well established, and is used at small- to medium-sized wastewater treatment plants throughout the U.S. Today, UV radiation to achieve high-level disinfection for reuse operations is acceptable in some states. In recognition of the possible harmful effects of chlorine, the Florida Department of Environmental Protection (FDEP) encourages the use of alternative disinfection methods (FDEP, 1996). The WERF published a final report entitled, “Disinfection Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance.” This report provides a broad-based discussion of the advantages and disadvantages of chlorine and UV, using an empirical model to determine the UV dose required for various levels of coliform inactivation. The report also includes cost information and a comparison of chlorination/dechlorination and UV systems (WERF, 1995). Studies in San Francisco, California, indicated that suspended solids play a major role in UV efficiency. This included the finding that, as the concentration of particles 7 mm and larger increase, the ability to achieve acceptable disinfection with UV decreases. Thus, filtration must be optimized to manage this problem (Jolis *et al.,* 1996).

The goal of UV disinfection in reuse applications typically is to inactivate 99.999 percent or more of the target pathogens (Swift *et al.,* 2002). The 2000 National Water Research Institute (NWRI) guidelines provide detailed guidance for the design of UV systems that will achieve high-level disinfection to meet some state standards for public access reuse. The 2000 NWRI guidelines also include a well-defined testing protocol and validation test as a means to provide reasonable assurance that the domestic wastewater treatment facility can meet the high-level disinfection criteria (NWRI and AWWA, 2000).

The Bethune Point WWTP in Daytona Beach, Florida, is the largest UV disinfection system in the state of Florida designed for reuse operations. This facility is also the first public access reuse facility in Florida with UV disinfection to be permitted for unrestricted public access (Elefritz, 2002). Placed into service in December 1999, the Bethune Point WWTP UV disinfection system is a medium pressure/high intensity system designed for a dose of 80mW-s/cm^2 (800 J/m^2) to achieve the high-level disinfection standard. The City of Henderson, Nevada water reclamation facility conducted collimated beam studies of a low pressure/high intensity UV disinfection system. The studies demonstrated that the disinfection goal of 20 fecal coliforms per 100 ml was achievable with a minimum UV dose of 200 J/m^2 (Smith and Brown, 2002).

Other disinfectants, such as onsite chlorine generation, gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater. These disinfectants are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

3.4.2.2 Advanced Wastewater Treatment

Advanced wastewater treatment processes are those beyond traditional secondary treatment. These processes are generally used when high quality reclaimed water is needed. Examples include: (1) urban landscaping, (2) food crops eaten raw, (3) contact recreation, and (4) many industrial applications. Individual unit processes capable of removing the constituents of concern are shown in **Figure 3-11**.

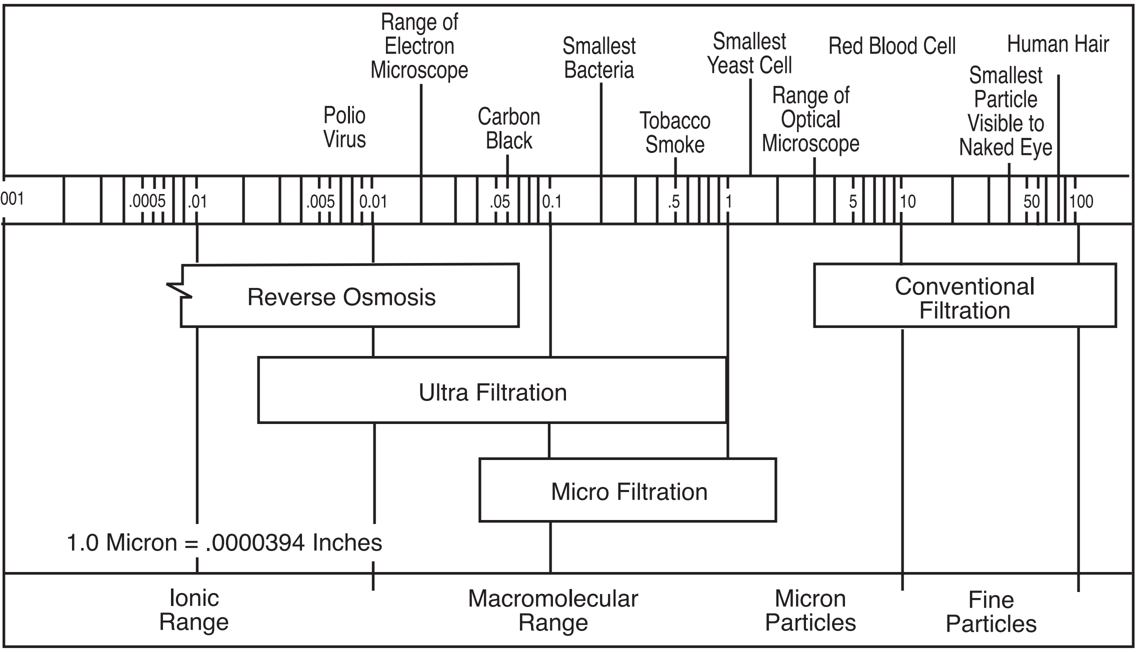
The principal advanced wastewater treatment processes for water reclamation are:

- Filtration – Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media or filter cloth, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants.

- UV Treatment of NDMA – UV Treatment, considered an Advanced Oxidation Technology (AOT), is the only proven treatment to effectively reduce NDMA. The adsorption of ultraviolet light, even the UV portion of sunlight, by NDMA causes the molecule to disassociate into harmless fragments (Nagel *et al.*, 2001). A study done at West Basin Municipal Water District in Carson, California proved NDMA concentrations were reduced by both low and medium pressure UV (Nagel *et al.*, 2001).

- Nitrification – Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to ni-

Figure 3-11. Particle Size Separation Comparison Chart



Adapted from AWWA, 1990

trite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts nitrogen into another chemical form. Nitrification can be achieved in many suspended and attached growth treatment processes when the processes are designed to foster the growth of nitrifying bacteria. In the traditional activated sludge process, this is accomplished by designing the process to operate at a solids retention time (SRT) that is long enough to prevent slow-growing nitrifying bacteria from being wasted out of the system. Nitrification will also occur in trickling filters that operate at low BOD/TKN ratios either in combination with BOD removal, or as a separate advanced treatment process following any type of secondary treatment. A well-designed and -operated nitrification process will produce an effluent containing 1.0 mg/l or less of ammonia nitrogen.

- Denitrification – Denitrification is any wastewater treatment method that completely removes total nitrogen. As with ammonia removal, denitrification is usually best achieved biologically, in which case it must be preceded by nitrification. In biological denitrification, nitrate nitrogen is used by a variety of heterotrophic bacteria as the terminal electron acceptor in the absence of dissolved oxygen. In the process, the nitrate nitrogen is converted to nitrogen gas, which escapes to the atmosphere. The bacteria in these processes also require a carbonaceous food source. Denitrification can be achieved using many alternative treatment processes including variations of many common suspended growth and some attached growth treatment processes, provided that the processes are designed to create the proper microbial environment. Biological denitrification processes can be designed to achieve effluent nitrogen concentrations between 2.0 and 12 mg/l of nitrate nitrogen.

- Phosphorus Removal – Phosphorus can be removed from wastewater through chemical or biological methods, or a combination. The choice of methods will depend on site-specific conditions, including the amount of phosphorus to be removed and the desired effluent phosphorus concentration. Chemical phosphorus removal is achieved by precipitating the phosphorus from solution through the addition of iron, aluminum, or calcium salts. Biological phosphorus removal relies on the culturing of bacteria that will store excess amounts of phosphorus when exposed to anaerobic conditions, followed by aerobic conditions in the treatment process. In both cases, the phosphorus is removed from the treatment process with the waste sludge. Chemical phosphorus removal can attain effluent orthophosphorus concentrations of less than 0.1 mg/l, while biological phosphorus removal will usually produce an effluent phosphorus concentration between 1.0 and 2.0 mg/l.

- Coagulation-Sedimentation – Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes SS, heavy metals, trace substances, phosphorus, and turbidity.

- Carbon Adsorption – One effective advanced wastewater treatment process for removing biodegradable and refractory organic constituents is granular activated carbon (GAC). Carbon adsorption can reduce the levels of synthetic organic chemicals in secondary effluent by 75 to 85 percent. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption proceeded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1 to 5.0 mg/l, a COD of 3 to 25 mg/l, and a TOC of 1 to 6 mg/l. Carbon adsorption treatment will also remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove uncharged species, such as arsenic and antimony, from an acidic stream. Carbon adsorption has also been reported as an effective means of removing endocrine disrupting compounds (Hunter and Long, 2002).

- Membrane Processes – In recent years, the same factors that favor the use of membranes for potable water treatment (increasing demand, decreasing source water quality, and more stringent regulatory standards) are influencing their use in treating wastewaters prior to reuse. Improvements in membrane technologies which separate suspended solids, dissolved compounds, and human pathogens (protozoan cysts, bacteria and viruses) from reclaimed water have inspired greater confidence in the use of reclaimed water for purposes which include both direct and indirect human contact.

  Membrane filters became commercially available in 1927 from the Sartorius Company in Germany. Until the mid-1940s, these filters were used primarily to remove microorganisms and particles from air and water. The first viable reverse osmosis membrane was developed in 1960 by researchers at the University of California at Los Angeles (UCLA). The first commercial reverse osmosis (RO) treatment plant went into service in 1965 in Coalinga, California. The use of membrane filtration systems was initially limited to specialized applications including industrial separation processes and seawater desalination. By the 1980s, membrane technology was well established.

For many years, membranes were not used for wastewater treatment due to rapid fouling. Prior to 1990, there were a few notable exceptions, including a highly publicized 5-mgd RO system at the Water Factory 21 reclamation plant in Orange County, California. This system went into service in 1975. The plant used cellulose acetate membranes with lime clarification and multi-media filtration for pretreatment prior to the RO system. Another notable exception was a 3.3-mgd (12 x 10^3-m^3/d) Petromin plant in Riyadh, Saudia Arabia.

The large-scale use of membranes for wastewater reclamation did not become feasible until the1980s, when the Australian firm, Memtec, developed a hollow fiber microfiltration membrane system with an air backwash that could provide sustainable operation for wastewater. The Orange County Water District (California) began pilot testing in 1992 to investigate this new microfiltration system as pretreatment for reverse osmosis. The use of this new microfiltration system, followed by thin film composite RO membranes, proved to be a tremendous improvement over the then-conventional system of lime clarification, sand filtration, and cellulose acetate membranes. Between 1994 and 2000, over half a dozen new dual membrane water reclamation systems were constructed in California and Arizona.

Pressure-driven membrane treatment systems are broadly categorized by the size particles rejected by the membrane, or by the molecular weight cut off (MWCO). These classifications include:

Microfiltration (MF)	0.1 μm	or	500, 000 MWCO
Ultrafiltration (UF)	0.01 μm	or	20,000 MWCO
Nanofiltration (NF)	0.001 μm	or	200 MWCO
Reverse Osmosis (RO)	0.0001 μm	or	< 100 MWCO

Figure 3-11 shows a particle size separation comparison chart for conventional filtration, microfiltration, ultrafiltration, and reverse osmosis. **Tables 3-13a** and **3-13b** contain microfiltration and reverse osmosis removal data (Metcalf and Eddy, 2002).

MF systems are used to remove relatively large suspended particles including particulates, large colloids, and oil. This includes providing about 3 to 6 log (99.9 percent to 99.9999 percent) removal of bacteria. In wastewater treatment, MF systems can be used to replace secondary clarifiers and more conventional (sand) filters following biological treatment. UF membranes have smaller pore sizes than MF membranes and will provide complete removal of bacteria and protozoan cysts, and 4 to 6 log removal for viruses. Otherwise, UF membranes perform the same basic functions in wastewater applications as MF membranes. NF and RO, while retaining smaller particles including molecules and ions, require higher driving pressures, higher levels of pretreatment (prefiltration), and typically operate at lower recovery rates.

For wastewater treatment, the main emphasis has been on MF, UF, and RO membranes. MF and UF have the ability to remove biological contaminants (e.g., bacteria and viruses), and to reduce fouling on downstream reverse osmosis membranes. NF or RO systems are needed where the removal of colloidal and/or dissolved materials is required.

Membrane Bioreactors (MBRs)

MBRs typically consist of UF or MF membranes. These membranes are used to replace conventional gravity clarifiers, and return activated sludge systems in conventional activated sludge biological treatment systems. The membranes can be immersed directly into the aeration tanks, or the mixed liquor can be pumped to external pressure-driven membrane units. MBRs exhibit a number of unique advantages:

- Sludge settling characteristics no longer affect final effluent quality. Biological processes can be operated at much higher suspended solids concentrations and thereby provide greater treatment capacity per unit volume.

- MF and UF membranes provide nearly complete removal of protozoan cysts, suspended solids, and bacteria, as well as partial removal of viruses. In addition to removing suspended solids, UF membranes can retain large organic molecules, improving the biodegradation of otherwise resistant compounds such as grease or emulsified oils.

- Longer sludge ages (as long as 30 to 45 days) are possible, improving the biodegradation of resistant compounds and improving nitrification performance under adverse conditions (such as low temperature).

- Wasting occurs directly from the aeration basin, improving process control.

- Submerged MBR systems are well suited to upgrade existing systems with minimum new construction required and low impact to ongoing operations.

Table 3-13a. Microfiltration Removal Performance Data

Constituent	MF Influent (mg/l)	MF Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	10-31	9-16	57	45-65
BOD	11-32	<2-9.9	86	75-90
COD	24-150	16-53	76	70-85
TSS	8-46	<0.5	97	95-98
TDS	498-622	498-622	0	0-2
NH_3-N	21-42	20-35	7	5-15
NO_3-N	<1-5	<1-5	0	0-2
PO_4^-	6-8	6-8	0	0-2
SO_4^{2-}	90-120	90-120	0	0-1
Cl^-	93-115	93-115	0	0-1
Turbidity	2-50 NTU	0.03-0.08 NTU	>99	---

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 2000 through December, 2000.

[2] Typical flux rate during test period was 1600 l/m²·d.

Adapted from: Metcalf and Eddy, 2002

Table 3-13b. Reverse Osmosis Performance Data

Constituent	RO Influent (mg/l)	RO Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	9-16	<0.5	>94	85-95
BOD	<2-9.9	<2	>40	30-60
COD	16-53	<2	>91	85-95
TSS	<0.5	~0	>99	95-100
TDS	498-622	9-19	---	90-98
NH_3-N	20-35	1-3	96	90-98
NO_3-N	<1-5	0.08-3.2	96	65-85
PO_4^-	8-Jun	0.1-1	~99	95-99
SO_4^{2-}	90-120	<0.5-0.7	99	95-99
Cl^-	93-115	0.9-5.0	97	90-98
Turbidity	0.03-0.08 NTU	0.03 NTU	50	40-80

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 1999 through December, 1999.

[2] Typical flux rate during test period was 348 l/m²·d.

Adapted from: Metcalf and Eddy, 2002

Submerged membrane assemblies, either MF or UF, are typically composed of bundles of hollow fiber or flat sheets of microporous membranes. Filtrate is drawn through the membrane assemblies by means of a vacuum applied to the product side of the membrane. Turbulence on the exterior (feed side) is maintained by diffused aeration to reduce fouling.

Low-pressure membrane filtration (MF or UF) can be used following secondary clarification to provide a higher degree of solids removal. Operating in a conventional (pressurized) flow pattern, clarified effluent is further treated to remove particulate material (MF) or colloidal material (UF). Typical operating pressures range from 20 to 100 psi (100 to 700 KPa), and reject flows range from 2 to 50 percent. MF and UF membranes can be used to pre-treat flow prior to NF or RO treatment.

Higher-pressure NF and RO systems are used to remove dissolved organic and inorganic compounds. The smaller pore size (lower MWCO) results in higher quality product water, which may meet primary and secondary drinking water standards. The higher rates of rejection also result in increasing problems for disposing of the concentrate streams.

- Other Processes – Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, and selective ion exchange for nitrogen removal.

3.4.3 Reliability in Treatment

A high standard of reliability, similar to water treatment plants, is required at wastewater reclamation plants. Because there is potential for harm (i.e., in the event that improperly treated reclaimed water is delivered to the use area), water reuse requires strict conformance to all applicable water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

A number of fallible elements combine to make up an operating water reclamation system. These include the power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. An array of design features and non-design provisions can be employed to improve the reliability of the separate elements and the system as a whole. Backup systems are important in maintaining reliability in the event of failure of vital components. Particularly critical units include the disinfection system, power supply, and various treatment unit processes.

For reclaimed water production, EPA Class I reliability is recommended as a minimum criteria. Class I reliability requires redundant facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse should also consider:

- Operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems

- Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions

- A comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol

- Adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal

- Supplemental storage and/or water supply to ensure that the supply can match user demands

- A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent illicit dumping into the collection system of hazardous materials or other materials that may interfere with the intended use of the reclaimed water

- A comprehensive operating protocol that defines the responsibilities and duties of the operations staff to ensure the reliable production and delivery of reclaimed water

Many states have incorporated procedures and practices into their reuse rules and guidelines to enhance the reliability of reclaimed water systems. Florida requires the producer of reclaimed water to develop a detailed operating protocol for all public access systems. This protocol must identify critical monitoring and control equipment, set points for chlorine and turbidity, actions to be taken in the event of a failure to achieve these limits, and procedures to clear the substandard water and return to normal operations (FAC 62-610). Washington is in the process of developing Water Reclamation Facilities Reliability Assessment Guidance, which includes an alarm and reliability checklist.

3.4.3.1 EPA Guidelines for Reliability

More than 30 years ago, before the Federal Water Quality Administration evolved into the EPA, it recognized the importance of treatment reliability, issuing guidelines entitled, “Federal Guidelines: Design, Operation and Maintenance of Waste Water Treatment Facilities” (Federal Water Quality Administration, 1970). These guidelines provided an identification and description of various reliability provisions and included the following concepts or principles regarding treatment plant reliability:

- All water pollution control facilities should be planned and designed to provide for maximum reliability at all times.
- Each facility should be capable of operating satisfactorily during power failures, flooding, peak loads, equipment failure, and maintenance shutdowns.
- Such reliability can be obtained through the use of various design techniques that will result in a facility that is virtually "fail-safe" (Federal Water Quality Administration, 1970).

The following points highlight more specific subjects for consideration in preparing final construction plans and specifications to help accomplish the above principles:

- Duplicate dual feed sources of electric power
- Standby onsite power for essential plant elements
- Multiple process units and equipment
- Holding tanks or basins to provide for emergency storage of overflow and adequate pump-back facilities
- Flexibility of piping and pumping facilities to permit rerouting of flows under emergency conditions
- Provision for emergency storage or disposal of sludge (Federal Water Quality Administration, 1970)

The non-design reliability features in the federal guidelines include provisions for qualified personnel, an effective monitoring program, and an effective maintenance and process control program. In addition to plans and specifications, the guidelines specify submission of a preliminary project planning and engineering report, which will clearly indicate compliance with the guideline principles.

In summary, the federal guidelines identify the following 8 design principles and 4 other significant factors that appear to be appropriate to consider for reuse operations:

<u>Design Factors</u>

Duplicate power sources

Standby power

Multiple units and equipment

Emergency storage

Piping and pumping flexibility

Dual chlorination systems

Automatic residual control

Automatic alarms

<u>Other Factors</u>

Engineering report

Qualified personnel

Effective monitoring program

Effective maintenance and process control program

In 1974, EPA subsequently published a document entitled, "Design Requirements for Mechanical, Electric, and Fluid Systems and Component Reliability" (U.S. EPA, 1974). While the purpose of that publication was to provide reliability design criteria for wastewater treatment facilities seeking federal financial assistance under PL 92-500, the criteria are useful for the design and operation of all wastewater treatment plants. These requirements established minimum standards of reliability for wastewater treatment facilities. Other important reliability design features include on-line monitoring (e.g., turbidimeters and chlorine residual analyzers, and chemical feed facilities.

Table 3-14 presents a summary of the equipment requirements under the EPA guidelines for Class I reliability treatment facilities.

As shown in Table 3-14, the integrity of the treatment system is enhanced by providing redundant, or oversized unit processes. This reliability level was originally specified for treatment plants discharging into water bodies that could be permanently or unacceptably damaged by improperly treated effluent. Locations where Class I facilities might be necessary are indicated as facilities discharging near drinking water reservoirs, into shellfish waters, or in proximity to areas used for water contact sports (U.S. EPA, 1974). While over 30 years old, the definition of Class I Reliability given in Table 3-14 is still referenced in the regulations of many states as the minimum level of reliability required for water reclamation projects.

Table 3-14. Summary of Class I Reliability Requirements

Unit	Class I Requirement
Mechanically-Cleaned Bar Screen	A back-up bar screen shall be provided (may be manually cleaned).
Pumps	A back-up pump shall be provided for each set of pumps which perform the same function. Design flow will be maintained with any 1 pump out of service.
Comminution Facilities	If comminution is provided, an overflow bypass with bar screen shall be provided.
Primary Sedimentation Basins	There shall be sufficient capacity such that a design flow capacity of 50 % of the total capacity will be maintained with the largest unit out of service.
Filters	There shall be a sufficient number of units of a size such that a design capacity of at least 75 % of the total flow will be maintained with 1 unit out of service.
Aeration Basins	At least 2 basins of equal volume will be provided.
Mechanical Aerator	At least 2 mechanical aerators shall be provided. Design oxygen transfer will be maintained with 1 unit out of service.
Chemical Flash Mixer	At least 2 basins or a back-up means of mixing chemicals separate from the basins shall be provided.
Final Sedimentation Basins	There shall be a sufficient number of units of a size such that 75% of the design capacity will be maintained with the largest unit out of service.
Flocculation Basins	At least 2 basins shall be provided.
Disinfectant Contact Basins	There shall be sufficient number of units of a size such that the capacity of 50% of the total design flow may be treated with the largest unit out of service.

Source: Adapted from U.S. Environmental Protection Agency, 1974

3.4.3.2 Additional Requirements for Reuse Applications

Different degrees of hazard are posed by process failures. From a public health standpoint, it is logical that a greater assurance of reliability should be required for a system producing reclaimed water for uses where direct or indirect human contact with the water is likely, than for water produced for uses where the possibility of contact is remote. Similarly, where specific constituents in reclaimed water may affect the acceptability of the water for any use (e.g., industrial process water), reliability directed at those constituents is important. Standby units or multiple units should be encouraged for the major treatment elements at all reclamation facilities. For small installations, the cost may be prohibitive and provision for emergency storage or disposal is a suitable alternative.

a. Piping and Pumping Flexibility

Process piping, equipment arrangements, and unit structures should provide for efficiency, ease of operation and maintenance, and maximum flexibility of operation. Flexibility plans should permit the necessary degree of treatment to be obtained under varying conditions. All aspects of plant design should allow for routine maintenance of treatment units without deterioration of the plant effluent.

No pipes or pumps should be installed that would circumvent critical treatment processes and possibly allow inadequately treated effluent to enter the reclaimed water distribution system. The facility should be capable of operating during power failures, peak loads, equipment failures, treatment plant upsets, and maintenance shutdowns. In some cases, it may be necessary to divert the wastewater to emergency storage facilities or discharge the wastewater to approved, non-reuse areas. During power failures or in the case of an equipment failure, standby portable diesel-driven pumps can also be used.

b. Emergency Storage or Disposal

The term "emergency storage or disposal" means to provide for the containment or alternative treatment and disposal of reclaimed water whenever the quality is not suitable for use. It refers to something other than normal operational or seasonal storage (e.g., storage that may be used to hold reclaimed water during wet weather times until it is needed for use). Provisions for emergency storage or disposal may be considered to be a basic reliability provision for some reclamation facilities. Where such provisions exist, they may substitute for multiple or standby units and other specific features.

Provisions for emergency storage or disposal may include:

- Holding ponds or tanks
- Approved alternative disposal locations such as percolation areas, evaporation-percolation ponds, or spray disposal areas
- Deep injection wells
- Pond systems having an approved discharge to receiving waters or discharge to a reclaimed water use area for which lower quality water is acceptable
- Provisions to return the wastewater to a sewer for subsequent treatment and disposal at the reclamation or other facility
- Any other facility reserved for the purpose of emergency storage or disposal of untreated or partially-treated wastewater

Automatically-actuated emergency or disposal provisions should include all of the necessary sensors, instruments, valves, and other devices to enable fully automatic diversion of the wastewater in the event of failure of a treatment process, and a manual reset to prevent automatic restart until the failure is corrected. For either manual or automatic diversion, all of the equipment other than the pump-back equipment should either be independent of the normal power source or provided with a standby power source. Irvine Ranch Water District in California automatically diverts its effluent to a pond when it exceeds a turbidity of 2 NTU. The water is then recirculated into the reclamation plant influent.

Where emergency storage is to be used as a reliability feature, storage capacity is an important consideration. This capacity should be based on estimates of how long it will take to return the facilities to normal operations and the penalties (regulatory or otherwise) associated with loss of treatment and discontinuation of reclaimed water service.

c. Alarms

Alarm systems should be installed at all water reclamation plants, particularly at plants that do not receive full-time attention from trained operators. Minimum instrumentation should consist of alarms at critical treatment units to alert an operator of a malfunction. This concept requires that the plant either be constantly attended, or that an operator be on call whenever the reclamation plant is in operation. In the latter case, a remote sounding device would be needed. If conditions are such that rapid attention to failures cannot be assured, automatically actuated emergency control mechanisms should be installed and maintained. Supervisory control and data acquisition (SCADA) systems may be employed to accomplish this objective, so long as information is made available to locations that are staffed when operators are not on site at the remote reclaimed water facilities. If a critical process were to fail, the condition may go unnoticed for an extended time period, and unsatisfactory reclaimed water would be produced for use. An alarm system will effectively warn of an interruption in treatment.

Requirements for warning systems may specify the measurement to be used as the control in determining a unit failure (e.g., dissolved oxygen) in an aeration chamber or the requirements could be more general in nature, merely specifying the units or processes that should be included in a warning system. The latter approach appears more desirable because it allows for more flexibility in the design. Alarms could be actuated in various ways, such as failure of power, high water level, failure of pumps or blowers, loss of dissolved oxygen, loss of coagulant feed, high head loss on filters, high effluent turbidity, or loss of disinfection.

In addition to the alarm system, it is critical to have a means available to take corrective action for each situation, which has caused the alarm to be activated. As noted above, provisions must be available to otherwise treat, store, or dispose of the wastewater until the corrections have been made. Alternative or supplemental features for different situations might include an automatic switchover mechanism to emergency power and a self-starting generator, or an automatic diversion mechanism which discharges wastewater from the various treatment units to emergency storage or disposal.

d. Instrumentation and Control

Major considerations in developing an instrumentation/ control system for a reclamation facility include:

- Ability to analyze appropriate parameters
- Ability to maintain, calibrate, and verify accuracy of on-line instruments
- Monitoring and control of treatment process performance
- Monitoring and control of reclaimed water distribution
- Methods of providing reliability
- Operator interface and system maintenance

The potential uses of the reclaimed water determine the degree of instrument sophistication and operator attention required in a water reuse system. For example, health risks may be insignificant for reclaimed water used for non-food crop irrigation. On the other hand, if wastewater is being treated for indirect potable reuse via groundwater recharge, risks are potentially high. Consequently, the instruments must be highly sensitive so that even minor discrepancies in water quality are detected rapidly.

Selection of monitoring instrumentation is governed by the following factors:

- Sensitivity
- Accuracy
- Effects of interferences
- Frequency of analysis and detection
- Laboratory or field application
- Analysis time
- Sampling limitations
- Laboratory requirements
- Acceptability of methods
- Physical location
- Ability to provide service and
- Reliability

Source: WPCF, 1989

Each water reclamation plant is unique, with its own requirements for an integrated monitoring and control instrumentation system. The process of selecting monitoring instrumentation should address aspects such as frequency of reporting, parameters to be measured, sample point locations, sensing techniques, future requirements, availability of trained staff, frequency of maintenance, availability of spare parts, and instrument reliability (WPCF, 1989). Such systems should be designed to detect operational problems during both routine and emergency operations. If an operating problem arises, activation of a signal or alarm permits personnel to correct the problem before an undesirable situation is created.

System control methods should provide for varying degrees of manual and automatic operation. Functions of control include the maintenance of operating parameters within preset limits, sequencing of physical operations in response to operational commands and modes, and automatic adjustment of parameters to compensate for variations in quality or operating efficiency.

System controls may be manual, automated, or a combination of manual and automated systems. For manual control, operations staff members are required to physically carry out all work tasks, such as closing and opening valves and starting and stopping pumps. For automated control, no operator input is required except for the initial input of operating parameters into the control system. In an automated control system, the system automatically performs operations such as the closing and opening of valves and the starting and stopping of pumps. These automated operations can be accomplished in a predefined sequence and timeframe and can also be initiated by a measured parameter.

Automatic controls can vary from simple float switches that start and stop pumps to highly sophisticated computer systems that gather data from numerous sources, compare the data to predefined parameters, and initiate actions in order to maintain system performance within required criteria. For example, in the backwashing of a filter, instrumentation that monitors head loss across a filter signals the automated control system that a predefined head loss value has been exceeded. The control system, in turn, initiates the backwashing sequence through the opening of valves and starting of pumps. A simple, but effective, means of maintaining control in the event of a power failure might include a judicious selection of how control valves respond to loss of power. For example, in a reuse system with a pair of control valves routing water either to customers or to a reject location, it is reasonable to expect that the valve to the customers should fail to the closed position, while the valve to reject would fail to the open position.

3.4.3.3 Operator Training and Competence

Regardless of the automation built into a plant, mechanical equipment is subject to breakdown, and qualified, well-trained operators are essential to ensure that the reclaimed water produced will be acceptable for its intended use. The facilities operation should be based on detailed process control with recording and monitoring facilities, a strict preventive maintenance schedule, and standard operating procedure contingency plans all structured to provide reliable product water quality.

The plant operator is considered to be the most critical reliability factor in the wastewater treatment system. All available mechanical reliability devices and the best possible plant design are to no avail if the operator is not capable and conscientious. Three operations personnel considerations influence reliability of treatment: operator attendance, operator competence, and operator training. The knowledge, skills, and abilities that an operator must possess varies, depending on the complexity of the plant. Most regulatory agencies require operator certification as a reasonable means to expect competent operation. Frequent training via continuing education courses or other means enhances operator competence.

Actions of the system operator have the potential to adversely affect water quality and public perception of the reclaimed water system. Therefore, a knowledgeable, attentive operator is critical to avoid potential threats to water quality. Consideration should be given to provide special training and certification for reclaimed water operations staff.

3.4.3.4 Quality Assurance in Monitoring

Quality assurance (QA) in monitoring of a reclamation program includes: (1) selecting the appropriate parameters to monitor, and (2) handling the necessary sampling and analysis in an acceptable manner. Sampling techniques, frequency, and location are critical elements of monitoring and quality assurance. Standard procedures for sample analysis may be found in the following references:

- *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, 1989)
- *Handbook for Analytical Quality Control in Water and Wastewater Laboratories* (U.S. EPA, 1979a)
- *Methods for Chemical Analysis of Water and Wastes* (U.S. EPA, 1983)
- *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater* (U.S. EPA, 1996)
- *Handbook for Sampling and Sample Preservation of Water and Wastewater* (U.S. EPA, 1982)

Typically, the QA plan associated with sampling and analysis is a defined protocol that sets forth data quality objectives and the means to develop quality control data. This serves to quantify precision, bias, and other reliability factors in a monitoring program. Strict adherence to written procedures ensures that the results are comparable, and that the level of uncertainty is verifiable.

Quality assurance/quality control (QA/QC) plans and procedures are well documented in referenced texts. QA/QC measures should be dictated by the severity of the consequences of acting on the “wrong answer” or on an “uncertain” answer. QA/QC procedures are often dictated by regulatory agencies, and do constitute necessary operating overhead. For reuse projects, this overhead may be greater than for wastewater treatment and disposal.

Sampling parameters required for reclamation extend beyond those common to wastewater treatment. For example, turbidity measurements are sometimes required for reclamation, but not for wastewater treatment and disposal. Monitoring for chlorides may be necessary for reuse in coastal communities.

Adequate record keeping of reclaimed water system operations is essential to the overall monitoring program. Many facilities find it reasonable and compatible with their usual practice and requirements to include routine reporting of plant operations and immediate notification of emergency conditions.

3.5 Seasonal Storage Requirements

Managing and allocating reclaimed water supplies may be significantly different from the management of traditional sources of water. Traditionally, a water utility drawing from groundwater or surface impoundments uses the resource as a source and as a storage facility. If the entire yield of the source is not required, the water is simply left for use at a later date. Yet in the case of reuse, reclaimed water is continuously generated, and what cannot be used immediately must be stored or disposed of in some manner.

Depending on the volume and pattern of projected reuse demands, seasonal surface storage requirements may become a significant design consideration and have a substantial impact on the capital cost of the system. Seasonal storage systems will also impact operational expenses. This is particularly true if the quality of the water is degraded in storage by algae growth and requires re-treatment to maintain the desired or required water quality. Pilot studies in California investigated the use of clarifiers with coagulation and continuous backwash filtration versus the use of dissolved air flotation with clarification and filtration. The estimated present worth costs of these 2 strategies for treating reclaimed water returned from storage ponds were calculated at \$1.92/gal (\$0.51/l) and \$2.17/gal (\$0.57/l), respectively (Fraser and Pan, 1998).

The need for seasonal storage in reclaimed water programs generally results from 1 of 2 requirements. First, storage may be required during periods of low demand for subsequent use during peak demand periods. Second, storage may be required to reduce or eliminate the discharge of excess reclaimed water into surface water or groundwater. These 2 needs for storage are not mutually exclusive, but different parameters are considered in developing an appropriate design for each one. In fact, projects where both water conservation and effluent disposal are important are more likely to be implemented than those with a single driver. Drivers for the creation of an urban reuse system in Tampa, Florida included water conservation as well as the fact that any reclaimed water diverted to beneficial reuse helped the City to meet its obligations to reduce nitrogen loadings to area surface waters (Grosh *et al.,* 2002). At the outset, it must be recognized that the use of traditional storage methods with finite capacities (e.g., tanks, ponds, and reservoirs) must be very large in comparison to the design flows in order to provide 100 percent equalization of seasonal supplies and demands. With an average flow of 18 mgd (68×10^3 m^3/d) and a storage volume of 1,600 million gallons (6×10^6 m^3), the City of Santa Rosa, California, still required a seasonal discharge to surface water to operate successfully (Cort *et al.,* 1998). After attempting to operate a 3.0 mgd (11×10^3 m^3/d) agricultural reuse system with 100 mg (0.4×10^6 m^3) of storage, Brevard County, Florida, decided to add manmade wetlands with a permitted surface water discharge as part of its wet weather management system (Martens *et al.,* 1998).

ASR of reclaimed water involves the injection of reclaimed water into a subsurface formation for storage, and recovery for beneficial use at a later time. ASR can be an effective and environmentally-sound approach by providing storage for reclaimed water used to irrigate areas accessible to the public, such as residential lawns and edible crops. These systems can minimize the seasonal fluctuations inherent to all reclaimed water systems by allowing storage of reclaimed water during the wet season when demand is low, and recovery of the stored water during dry periods when demand is high. Because the potential storage volume of an ASR system is essentially unlimited, it is expected that these systems will offer a solution to the shortcomings of the traditional storage techniques discussed above.

The use of ASR was also considered as part of the Monterey County, California reuse program in order to overcome seasonal storage issues associated with an irrigation-based project (Jaques and Williams, 1996).

Where water reuse is being implemented to reduce or eliminate wastewater discharges to surface waters, state or local regulations usually require that adequate storage be provided to retain excess wastewater under a specific return period of low demand. In some cold climate states, storage volumes may be specified according to projected non-application days due to freezing temperatures. Failure to retain reclaimed water under the prescribed weather conditions may constitute a violation of an NPDES permit and result in penalties. A method for preparing storage calculations under low demand conditions is provided in the EPA *Process Design Manual: Land Treatment of Municipal Wastewater* (U.S. EPA, 1981 and 1984). In many cases, state regulations will also include a discussion about the methods to be used for calculating the storage that is required to retain water under a given rainfall or low demand return interval. In almost all cases, these methods will be aimed at demonstrating sites with hydrogeologic storage capacity to receive wastewater effluent for the purposes of disposal. In this regard, significant attention is paid to subsurface conditions as they apply to the percolation of effluent into the groundwater with specific concerns as to how the groundwater mound will respond to effluent loading.

The remainder of this section discusses the design considerations for seasonal storage systems. For the purpose of discussion, the projected irrigation demands of turf grass in a hot, humid location (Florida) and a hot, arid location (California) are used to illustrate storage calculations. Irrigation demands were selected for illustration because irrigation is a common use of reclaimed water, and irrigation demands exhibit the largest seasonal fluctuations, which can affect system reliability. However, the general methodologies described in this section can also be applied to other uses of reclaimed water and other locations as long as the appropriate parameters are defined.

3.5.1 Identifying the Operating Parameters

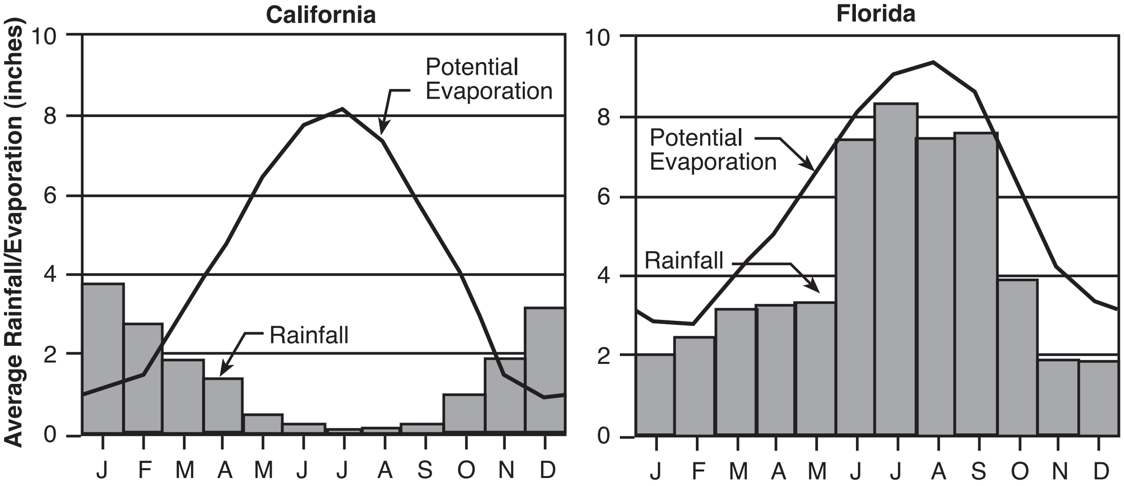
In many cases, a water reuse system will provide reclaimed water to a diverse customer base. Urban reuse customers typically include golf courses and parks and may also include commercial and industrial customers. Such is the case in both the City of St. Petersburg, Florida, and Irvine Ranch Water District, California, reuse programs. These programs provide water for cooling, washdown, and toilet flushing as well as for irrigation. Each water use has a distinctive seasonal demand pattern and, thereby, impacts the need for storage.

Reuse systems have significant differences with traditional land application systems starting with the fundamental objectives of each. Land application systems seek to maximize hydraulic loadings while reuse systems provide nonpotable waters for uses where a higher quality of water is not required. Historical water use patterns should be used where available. Methodologies developed for land application systems are generally poorly suited to define expected demands of an irrigation-based reuse system and should be replaced with methodologies expressly developed to estimate irrigation needs. This point was illustrated well by calculations of storage required to prevent a discharge based on: (1) actual golf course irrigation use over a 5-year period and (2) use of traditional land application water balance methods using site-specific hydrogeological information and temperature and rainfall corresponding to the 5-year record of actual use. Use of historical records estimated a required storage volume of 89 days of flow, while traditional land application methods estimated a required storage volume of 196 days (Ammerman *et al.,* 1997). It should also be noted that, like potable water, the use of reclaimed water is subject to the customer's perceived need for water.

The primary factors controlling the need for supplemental irrigation are evapotranspiration and rainfall. Evapotranspiration is strongly influenced by temperature and will be lowest in the winter months and highest in midsummer. Water use for irrigation will also be strongly affected by the end user and their attention to the need for supplemental water. Where uses other than irrigation are being investigated, other factors will be the driving force for demand. For example, demand for reclaimed water for industrial reuse will depend on the needs of the specific industrial facility. These demands could be estimated based on past water use records, if data are available, or a review of the water use practices of a given industry. When considering the demand for water in a manmade wetland, the system must receive water at the necessary time and rate to ensure that the appropriate hydroperiod is simulated. If multiple uses of reclaimed water are planned from a single source, the factors affecting the demand of each should be identified and integrated into a composite system demand.

Figure 3-12 presents the average monthly potential evaporation and average monthly rainfall in southwest Florida and Davis, California (Pettygrove and Asano,

Figure 3-12. Average Monthly Rainfall and Pan Evaporation



1985). The average annual rainfall is approximately 52 inches (132 cm) per year, with an average annual potential evaporation of 71 inches (180 cm) per year in Florida. The average annual rainfall in Davis is approximately 17 inches (43 cm) per year with a total annual average potential evaporation rate of approximately 52 inches (132 cm) per year.

In both locations, the shape of the potential evaporation curve is similar over the course of the year; however, the distribution of rainfall at the sites differs significantly. In California, rainfall is restricted to the late fall, winter, and early spring, with little rainfall expected in the summer months when evaporation rates are the greatest. The converse is true for the Florida location, where the major portion of the total annual rainfall occurs between June and September.

3.5.2 Storage to Meet Irrigation Demands

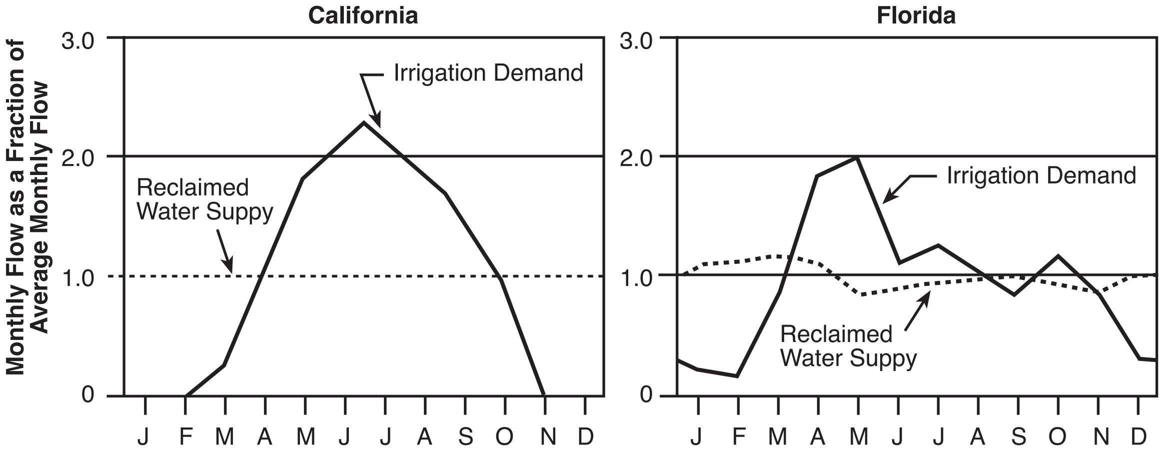
Once seasonal evapotranspiration and rainfall have been identified, reclaimed water irrigation demands throughout the seasons can be estimated. The expected fluctuations in the monthly need for irrigation of grass in Florida and California are presented in **Figure 3-13.** The figure also illustrates the seasonal variation in wastewater flows and the potential supply of irrigation water for both locations. In both locations, the potential monthly supply and demand are expressed as a fraction of the average monthly supply and demand.

To define the expected fluctuations in Florida's reclaimed water supply, historic flow data are averaged for each month. The reclaimed water supply for the Florida example indicates elevated flows in the late winter and early spring with less than average flows in the summer months, reflecting the region's seasonal influx of tourists. The seasonal irrigation demand for reclaimed water in Florida was calculated using the Thornthwaite equation. (Withers and Vipond, 1980). It is interesting to note that even in months where rainfall is almost equal to the potential evapotranspiration, a significant amount of supplemental irrigation may still be required. This occurs as a result of high intensity, short duration, rainfalls in Florida coupled with the relatively poor water-holding capacity of the surficial soils.

The average monthly irrigation demand for California, shown in Figure 3-12, is based on data developed by Pruitt and Snyder (Pettygrove and Asano, 1985). Because significant rainfall is absent throughout most of the growing season, the seasonal pattern of supplemental irrigation for the California site is notably different from that of Florida. For the California example, it has been assumed that there is very little seasonal fluctuation in the potential supply of reclaimed water. If the expected annual average demands of a reclaimed water system are approximately equal to the average annual available supply, storage is required to hold water for peak demand months. Using monthly supply and demand factors, the required storage can be obtained from the cumulative supply and demand. The results of this analysis suggest that, to make beneficial use of all available water under average conditions, the Florida reuse program will require approximately 90 days of storage, while California will need approximately 150 days.

These calculations are based on the estimated consumptive demand of the turf grass. In actual practice, the estimate would be refined, based on site-specific conditions. Such conditions may include the need to leach

Figure 3-13. Average Pasture Irrigation Demand and Potential Supply



salts from the root zone or to intentionally over-apply water as a means of disposal. The vegetative cover receiving irrigation will also impact the condition under which supplemental water will be required. Drought conditions will result in an increased need for irrigation. The requirements of a system to accommodate annual irrigation demands under drought conditions should also be examined.

3.5.3 Operating without Seasonal Storage

Given the challenges of using storage to equalize seasonal supplies and demands, it is not surprising that many utilities choose to commit only a portion of the available reclaimed water flow to beneficial reuse.

A partial commitment of reclaimed water may also have applications in the following situations:

- The cost of providing storage for the entire flow is prohibitive
- Sufficient demand for the total flow is not available
- The cost of developing transmission facilities for the entire flow is prohibitive
- Total abandonment of existing disposal facilities is not cost-effective

Systems designed to use only a portion of the reclaimed water supply are plentiful. It should be noted that a partial commitment of reclaimed water may be able to achieve significant benefits in terms of environmental impacts. Specifically, many surface water discharge permits are based on the 7-day, 10-year (7Q10) low flow expected in the receiving water body. Such events invariably coincide with extended periods of low rainfall, which, in turn, tend to increase the amount of water diverted away from disposal and into the reuse system.

3.6 Supplemental Water Reuse System Facilities

3.6.1 Conveyance and Distribution Facilities

The distribution network includes pipelines, pump stations, and storage facilities. No single factor is likely to influence the cost of water reclamation more than the conveyance or distribution of reclaimed water from its source to its point of use. The design requirements of reclaimed water conveyance systems vary according to the needs of the users. Water quality is, of course, a consideration as well. Reclaimed water systems may present more challenges for both internal and external corrosion than typically experienced in the potable water system. Generally, reclaimed water is more mineralized with a higher conductance and chloride content and lower pH, enhancing the potential for corrosion on the interior of the pipe. Because reclaimed water lines are often the last pipe installed, there is an increased opportunity for stray current electrolysis or coating damage (Ryder, 1996). Design requirements will also be affected by the policies governing the reclamation system (e.g., what level of shortfall, if any, can be tolerated?). Where a dual distribution system is created, the design will be similar to that of a potable system in terms of pressure and volume requirements. However, if the reclaimed water distribution system does not provide for an essential service such as fire protection or sanitary uses, the reliability of the reclamation system need not be as stringent. This, in turn, reduces the need for backup systems, thereby reducing the cost of the system. In addition, an urban reuse program designed primarily for irrigation will experience diurnal and seasonal flows and peak demands that have different design parameters than the fire protection requirements generally used in the design of potable water systems.

The target customer for many reuse programs may be an entity that is not traditionally part of municipal water/wastewater systems. Such is the case with agricultural and large green space areas, such as golf courses, that often rely on wells to provide for nonpotable water uses. Even when these sites are not directly connected to municipal water supplies, reclaimed water service to these customers may be desirable for the following reasons:

- The potential user currently draws water from the same source as that used for potable water, creating an indirect demand on the potable system.
- The potential user has a significant demand for nonpotable water and reuse may provide a cost-effective means to reduce or eliminate reliance on existing effluent disposal methods.
- The potential user is seeking reclaimed water service to enhance the quality or quantity (or both) of the water available.
- A municipal supplier is seeking an exchange of nonpotable reclaimed water for raw water sources currently controlled by the prospective customer.

The conveyance and distribution needs of these sites may vary widely and be unfamiliar to a municipality. For example, a golf course may require flows of 500 gpm (38 l/s) at pressures of 120 psi (830 kPa). However, if the golf course has the ability to store and repump irrigation water, as is often the case, reclaimed water can be delivered at atmospheric pressure to a pond at approximately one-third the instantaneous demand. Where frost-sensitive crops are served, an agricultural customer may wish to provide freeze protection through the irrigation system. Accommodating this may increase peak flows by an order of magnitude. Where customers that have no history of usage on the potable system are to be served with reclaimed water, detailed investigations are warranted to ensure that the service provided would be compatible with the user needs. These investigations should include an interview with the system operator as well as an inspection of the existing facilities.

Figure 3-14 provides a schematic of the multiple reuse conveyance and distribution systems that may be encountered. The actual requirements of a system will be dictated by the final customer base and are discussed in Chapter 2. The remainder of this section discusses issues pertinent to all reclaimed water conveyance and distribution systems.

A concentration or cluster of users results in lower customer costs for both capital and O&M expenses than a delivery system to dispersed users. Initially, a primary skeletal system is generally designed to serve large institutional users who are clustered and closest to the treatment plant. A second phase may then expand the system to more scattered and smaller users, which receive nonpotable water from the central arteries of the nonpotable system. Such an approach was successfully implemented in the City of St. Petersburg, Florida. The initial customers were institutional (e.g., schools, golf courses, urban green space, and commercial). However, the lines were sized to make allowance for future service to residential customers.

As illustrated in St. Petersburg and elsewhere, once reclaimed water is made available to large users, a secondary customer base of smaller users often request service. To ensure that expansion can occur to the projected future markets, the initial system design should model sizing of pipes to satisfy future customers within any given zone within the service area. At points in the system, where a future network of connections is anticipated, such as a neighborhood, turnouts should be installed. Pump stations and other major facilities involved in conveyance should be designed to allow for planned expansion. Space should be provided for additional pumps, or the capacities of the pumps may be expanded by changes to impellers and/or motor size. Increasing a pipe diameter by one size is economically justified since over half the initial cost of installing a pipeline is for excavation, backfill, and pavement.

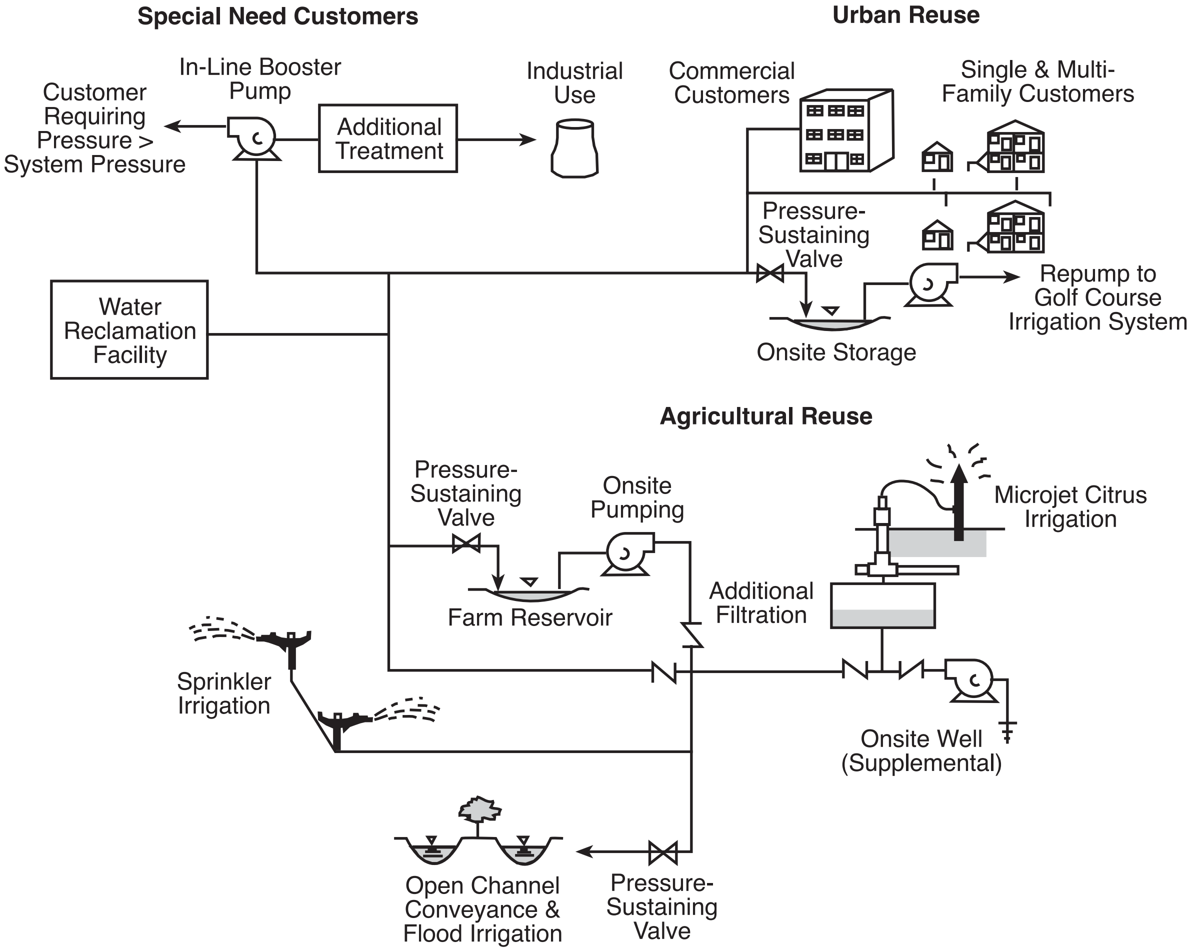
A potable water supply system is designed to provide round-the-clock, “on-demand” service. Some nonpotable systems allow for unrestricted use, while others place limits on the hours when service is available. A decision on how the system will be operated will significantly affect system design. Restricted hours for irrigation (i.e., only evening hours) may shift peak demand and require greater pumping capacity than if the water was used over an entire day or may necessitate a programmed irrigation cycle to reduce peak demand. The Irvine Ranch Water District, California, though it is an “on-demand” system, restricts landscape irrigation to the hours of 9 p.m. to 6 a.m. to limit public exposure. Due to the automatic timing used in most applications, the peak hour demand was found to be 6 times the average daily demand and triple that of the domestic water distribution system (Young *et al*., 1987). The San Antonio Water System (Texas) established a requirement for onsite storage for all users with a demand greater than 100 acre-feet per year as a means of managing peak demands. As noted previously, attributes such as freeze protection may result in similar increases in peak demands of agricultural systems.

System pressure should be adequate to meet the user’s needs within the reliability limits specified in a user agreement or by local ordinance. The Irvine Ranch Water District, California runs its system at a minimum of 90 psi (600 kPa). The City of St. Petersburg, Florida currently operates its system at a minimum pressure of 60 psi (400 kPa). However, the City of St. Petersburg is recommending that users install low-pressure irrigation devices, which operate at 50 psi (340 kPa) as a way of transferring to a lower pressure system in the future to reduce operating costs. The City of Orlando, Florida is designing a regional urban reuse system with a target minimum pressure in the transmission main of 50 psi (350 KPa) at peak hour conditions (CDM, 2001).

When significant differences in elevations exist within the service area, the system should be divided into pressure zones. Within each zone, a maximum and minimum delivery pressure is established. Minimum delivery pressures may be as low as 10 psi (70 kPa) and maximum delivery pressures may be as high as 150 psi (1,000 kPa), depending on the primary uses of the water.

Several existing guidelines recommend operating the nonpotable system at pressures lower than the potable system (i.e., 10 psi, 70 kPa lower) in order to mitigate any cross-connections. However, experience in the field indicates that this is difficult to achieve at all times throughout the distribution system.

Figure 3-14. Example of a Multiple Reuse Distribution System



3.6.1.1 Public Health Safeguards

The major concern guiding design, construction, and operation of a reclaimed water distribution system is the prevention of cross-connections. A cross-connection is a physical connection between a potable water system used to supply water for drinking purposes, and any source containing nonpotable water through which potable water could be contaminated.

Another major concern is to prevent improper use or inadvertent use of reclaimed water as potable water. To protect public health from the outset, a reclaimed water distribution system should be accompanied by health codes, procedures for approval (and disconnection) of service, regulations governing design and construction specifications, inspections, and operation and maintenance staffing. Public health protection measures that should be addressed in the planning phase are identified below.

- Establish that public health is the overriding concern
- Devise procedures and regulations to prevent cross-connections
- Develop a uniform system to mark all nonpotable components of the system
- Prevent improper or unintended use of nonpotable water through a proactive public information program
- Provide for routine monitoring and surveillance of the nonpotable system
- Establish and train special staff members to be responsible for operations, maintenance, inspection, and approval of reuse connections
- Develop construction and design standards

- Provide for the physical separation of the potable water, reclaimed water, sewer lines and appurtenances

Successful methods for implementing these measures are outlined below.

a. Identification of Pipes and Appurtenances

All components and appurtenances of the nonpotable system should be clearly and consistently identified throughout the system. Identification should be through color coding and marking. The nonpotable system (i.e., pipes, pumps, outlets, and valve boxes) should be distinctly set apart from the potable system. The methods most commonly used are unique colorings, labeling, and markings.

Nonpotable piping and appurtenances are painted purple or can be integrally stamped or marked, "CAUTION NONPOTABLE WATER – DO NOT DRINK" or "CAUTION: RECLAIMED WATER – DO NOT DRINK," or the pipe may be wrapped in purple polyethylene vinyl wrap. Another identification method is to mark pipe with colored marking tape or adhesive vinyl tape. When tape is used, the words ("CAUTION: RECLAIMED WATER – DO NOT DRINK") should be equal to the diameter of the pipe and placed longitudinally at 3-feet (0.9-meters) intervals. Other methods of identification and warning are: stenciled pipe with 2- to 3-inch (5- to 8-cm) letters on opposite sides, placed every 3 to 4 feet (0.9 to 1.2 meters); for pipe less than 2 inches (5 cm), lettering should be at least 5/8-inch (1.6 cm) at 1-foot (30-cm) intervals; plastic marking tape (with or without metallic tracer) with lettering equal to the diameter of pipe, continuous over the length of pipe at no more than 5-foot (1.5-meter) intervals; vinyl adhesive tape may be placed at the top of the pipe for diameters 2.5 to 3 inches (6 to 8 cm) and along opposite sides of the pipe for diameters 6 to 16 inches (15 to 40 cm), and along both sides and on top of the pipe for diameters of 20 inches (51 cm) or greater (AWWA, 1994).

The FDEP requires all new advisory signs and labels on vaults, service boxes, or compartments that house hose bibs, along with all labels on hose bibs, valves, and outlets, to bear the words, "do not drink" and "no beber," along with the equivalent standard international symbol. In addition to the words, "do not drink" and "no beber," advisory signs posted at storage ponds and decorative water features also bear the words, "do not swim" and "no nadar," along with the equivalent standard international symbols. **Figure 3-15** shows a typical reclaimed water advisory sign. Existing advisory signs and labels will be retrofitted, modified, or replaced in order to comply with the revised wording requirements as part of the permit renewal process for FDEP (FDEP, 1999).

Figure 3-15. Reclaimed Water Advisory Sign

Valve boxes for hydraulic and electrical components should be colored and warnings should be stamped on the cover. The valve covers for nonpotable transmission lines should not be interchangeable with potable water covers. For example, the City of Altamonte Springs, Florida uses square valve covers for reclaimed water and round valve covers for potable water. Blow-off valves should be painted and carry markings similar to other system piping. Irrigation and other control devices should be marked both inside and outside. Any constraints or special instructions should be clearly noted and placed in a suitable cabinet. If fire hydrants are part of the system, they should be painted or marked and the stem should require a special wrench for opening.

b. Horizontal and Vertical Separation of Potable from Nonpotable Pipes

The general rule is that a 10-foot (3-meter) horizontal interval and a 1-foot (0.3-meter) vertical distance should be maintained between potable (or sewer) lines and nonpotable lines that are parallel to each other. When these distances cannot be maintained, special authorization may be required, though a minimum lateral distance of 4 feet (1.2 meters) (St. Petersburg) is generally mandatory. The State of Florida specifies a 5-foot (1.5-meter) separation between reclaimed water lines and water lines or force mains, with a minimum of 3-foot (0.9-meter) separation from pipe wall to pipe wall (FDEP, 1999). This arrangement allows for the installation of reclaimed water lines between water and force mains that are separated by 10 feet (3 meters). The potable water should be placed above the nonpotable, if possible. Under some circumstances, using a reclaimed water main of a different depth than that of potable or force mains might be considered to provide further protection from having an inadvertent cross–connection occur. Nonpotable lines are usually required to be at least 3 feet (90 cm) below ground. **Figure 3-16** illustrates Florida's separation requirements for nonpotable lines.

c. Prevent Onsite Ability to Tie into Reclaimed Water Lines

The Irvine Ranch Water District, California has regulations mandating the use of special quick coupling valves for onsite irrigation connections. For reclaimed water, these valves are operated by a key with an Acme thread. This thread is not allowed for the potable system. The cover on the reclaimed water coupler is different in color and material from that used on the potable system. Hose bibs are generally not permitted on nonpotable systems because of the potential for incidental use and possible human contact with the reclaimed water. Below-ground bibs placed inside a locking box or that require a special tool to operate are allowed by Florida regulations (FDEP, 1999).

d. Backflow Prevention

Where the possibility of cross-connection between potable and reclaimed water lines exists, backflow prevention devices should be installed onsite when both potable and reclaimed water services are provided to a user. The backflow prevention device is placed on the potable water service line to prevent potential backflow from the reclaimed water system into the potable water system if the 2 systems are illegally interconnected. Accepted methods of backflow prevention include:

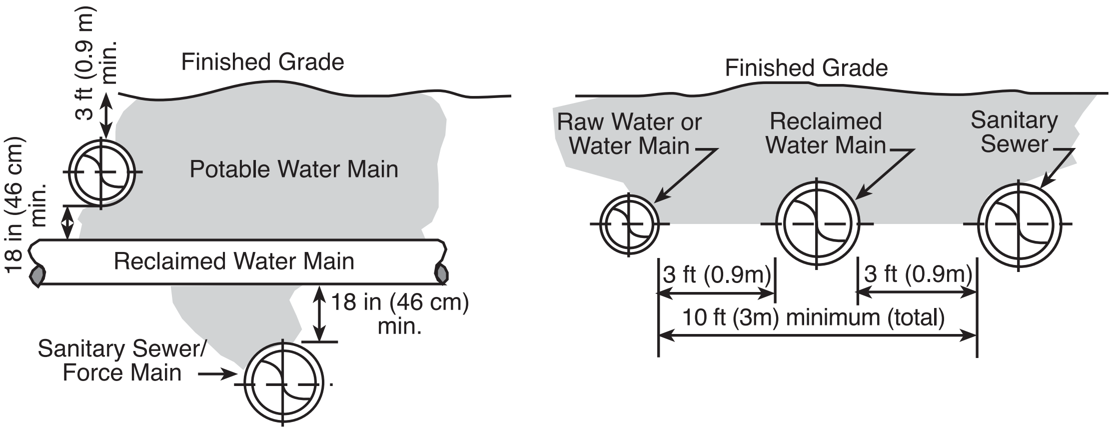
- Air gap
- Reduced-pressure principal backflow prevention assembly
- Double-check valve assembly
- Pressure vacuum breaker
- Atmospheric vacuum breaker

The AWWA recommends the use of a reduced-pressure principal backflow prevention assembly where reclaimed water systems are present. However, many communities have successfully used double-check valve assemblies. The backflow prevention device will prevent water expansion into the water distribution system. At some residences, the tightly closed residential water system can create a pressure buildup that causes the safety relief on a water heater to periodically discharge. This problem was solved by the City of St. Petersburg, Florida, by providing separate pressure release valves, which allow for the release of water through an outdoor hose bibb.

If potable water is used as make-up water for lakes or reservoirs, there should be a physical break between the potable water supply pipe and receiving reservoir. The air gap separating the potable water from the reservoir containing nonpotable water should be at least 2 pipe diameters. There should never be any permanent connection between nonpotable and potable lines in the system.

In most cases, backflow prevention devices are not provided on a reclaimed water system. However, the San Antonio Water System (Texas) requires a reduced-pres-

Figure 3-16. Florida Separation Requirements for Reclaimed Water Mains



sure principal backflow preventer on the potable supply to properties using reclaimed water. In addition, the City requires customers to use a double-check assembly or air gap on the reclaimed water supply. This provision is basic to maintaining a consistent water quality in the San Antonio reclaimed water supply. It is prudent to periodically inspect the potable system to confirm that cross-connections do not exist. The City of San Antonio alternately shuts down the potable and reclaimed water at a site. The inactive system is then checked for residual pressure, indicating a cross- connection. Where possible, dye tests are also conducted (Baird, 2000). The City of Altamonte Springs, Florida takes its entire reuse system off line for 2 days each year as part of its cross-connection control program.

e. Safeguards when Converting Existing Potable Lines to Nonpotable Use

In cases where parts of the system are being upgraded and some of the abandoned potable water lines are being transferred to the nonpotable system, care must be taken to prevent any cross-connections from occurring. As each section is completed, the new system should be shutdown and drained and each water user checked to ensure that there are no improper connections. Additionally, a tracer, such as potassium permanganate, may be introduced into the nonpotable system to test whether any of it shows up at any potable fixture.

In existing developments where an in-place irrigation system is being converted to carry reclaimed water, the new installation must be inspected and tested with tracers or some other method to ensure separation of the potable from the nonpotable supply. It may warrant providing a new potable service line to isolated potable facilities. For example, if a park is converting to reclaimed water, rather than performing an exhaustive evaluation to determine how a water fountain was connected to the existing irrigation system, it could be simpler to supply a new service lateral from the new water main.

3.6.1.2 Operations and Maintenance

Maintenance requirements for the nonpotable components of the reclaimed water distribution system should be the same as those for potable. As the system matures, any disruption of service due to operational failures will upset the users. From the outset, such items as isolation valves, which allow for repair to parts of the system without affecting a large area, should be designed into the nonpotable system. Flushing the line after construction should be mandatory to prevent sediment from accumulating, hardening, and becoming a serious future maintenance problem.

Differences in maintenance procedures for potable and nonpotable systems cannot generally be forecast prior to the operation of each system. For instance, the City of St. Petersburg, Florida flushes its nonpotable lines twice a year during the off-season months. The amount of water used in the flushing is equal to a day's demand of reclaimed water. The Irvine Ranch Water District (California) reports no significant difference in the 2 lines, though the reclaimed lines are flushed more frequently (every 2 to 3 years versus every 5 to 10 years for potable) due to suspended matter and sediment picked up during lake storage. Verification that adequate disinfection has occurred as part of treatment prior to distribution to reclaimed water customers is always required. However, maintenance of a residual in the transmission/distribution system is not required. Florida requires a 1-mg/l chlorine residual at the discharge of the chlorine contact basin, but no minimum residual is required in the reclaimed water piping system. The State of Washington is an exception in that it does require a minimum of 0.5-mg/l-chlorine residual in the distribution lines.

a. Blow-Offs/Flushing Hydrants

Even with sufficient chlorination, residual organics and bacteria may grow at dead spots in the system, which may lead to odor and clogging problems. Flushing and periodic maintenance of the system can significantly allay the problem. In most cases, the flushing flow is directed into the sewage system.

b. Flow Recording

Even when a system is unmetered, accurate flow recording is essential to manage the growth of the system. Flow data are needed to confirm total system use and spatial distribution of water supplied. Such data allow for efficient management of the reclaimed water pump stations and formulations of policies to guide system growth. Meters placed at the treatment facility may record total flow and flow-monitoring devices may be placed along the system, particularly in high consumption areas.

c. Permitting and Inspection

The permitting process includes plan and field reviews followed by periodic inspections of facilities. This oversight includes inspection of both onsite and offsite facilities. Onsite facilities are the user's nonpotable water facilities downstream from the reclaimed water meter. Offsite facilities are the agency's nonpotable water facilities up to and including the reclaimed water meter.

Though inspection and review regulations vary from system to system, the basic procedures are essentially the same. These steps are described below.

(1) Plan Review – A contractor (or resident) must request service and sign an agreement with the agency or department responsible for permitting reclaimed water service. Dimensioned plans and specifications for onsite facilities must conform to regulations. Usually, the only differences from normal irrigation equipment will be identification requirements and special appurtenances to prevent cross-connections. Some systems, however, require that special strainer screens be placed before the pressure regulator for protection against slime growths fouling the sprinkler system, meter, or pressure regulator.

The plans are reviewed and the agency works with the contractor to make sure that the system meets all requirements. Systems with cross-connections to potable water systems must be denied. Temporary systems should not be considered. Devices for any purpose other than irrigation should be approved through special procedures.

Installation procedures called out on the plan notes are also reviewed because they provide the binding direction to the landscape contractor. All points of connection are reviewed for safety and compatibility. The approved record drawings ("as-builts") are kept on file. The "as-builts" include all onsite and offsite nonpotable water facilities as constructed or modified, and all potable water and sewer lines.

(2) Field Review – Field review is generally conducted by the same staff involved in the plan review. Staff looks for improper connections, unclear markings, and insufficient depths of pipe installation. A cross-connection control test is performed, followed by operation of the actual onsite irrigation system to ensure that overspraying and overwatering are not occurring. Any problems identified are then corrected. Follow-up inspections are routine, and in some cases, fixed interval (e.g. semi-annual) inspections and random inspections are planned.

(3) Monitoring – A number of items should be carefully monitored or verified, including:

- Requiring that landscape contractors or irrigation contractors provide at least minimal education to their personnel so that these contractors are familiar with the regulations governing reclaimed water installations
- Submitting all modifications to approved facilities to the responsible agencies
- Detecting and recording any breaks in the transmission main
- Randomly inspecting user sites to detect any faulty equipment or unauthorized use
- Installing monitoring stations throughout the system to test pressure, chlorine residual, and other water quality parameters

A reclaimed water supplier should reserve the right to withdraw service for any offending condition subject to correction of the problem. Such rights are often established as part of a user agreement or a reuse ordinance. Chapter 5 provides a discussion of the legal issues associated with reclaimed water projects.

3.6.2 Operational Storage

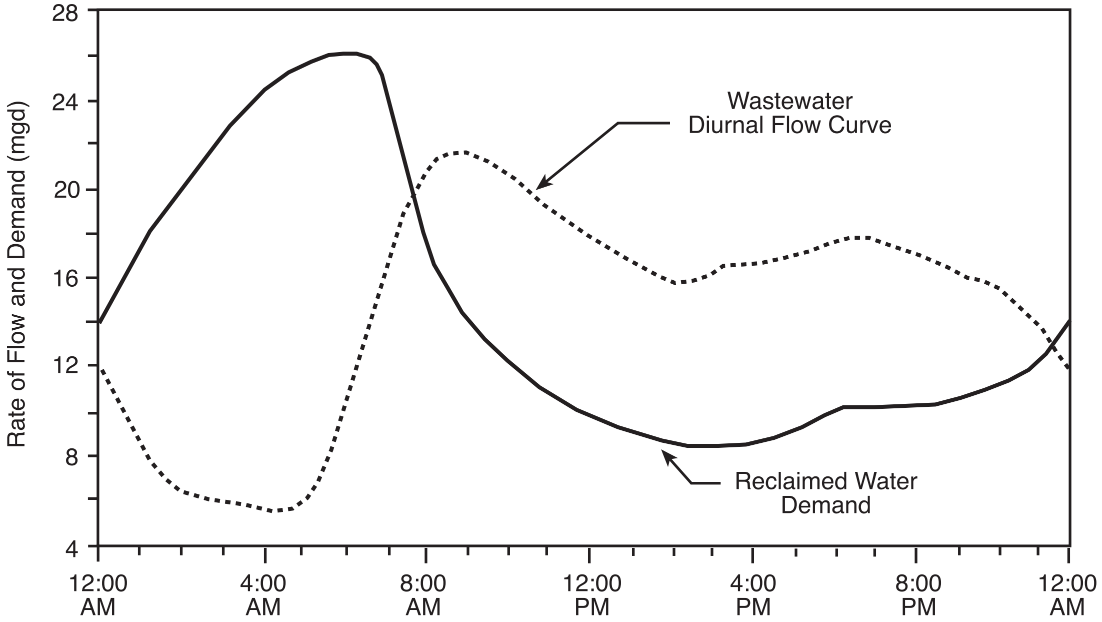
As with potable water distribution systems, a reclaimed water system must provide sufficient operational storage to accommodate diurnal fluctuations in demand and supply. The volume required to accommodate this task will depend on the interaction of the supply and demand over a 24-hour period.

Designs are dependent on assessments of the diurnal demand for reclaimed water. Such assessments, in most cases, require a detailed investigation of the proposed user or users. When possible, records of actual historical use should be examined as a means to develop demand requirements. Where records are absent, site-specific investigations are in order. In some cases, pilot studies may be warranted prior to initiating a full-scale reuse program.

Figure 3-17 presents the anticipated diurnal fluctuation of supply and urban irrigation demand for a proposed reclaimed water system in Boca Raton, Florida (CDM, 1991). This information was developed based on the historic fluctuations in wastewater flow experienced in Boca Raton and the approximate fluctuations in the reclaimed water urban irrigation demand experienced in the St. Petersburg, Florida urban reuse program.

Operational storage may be provided at the reclamation facility, as remote storage out in the system, or as a combination of both. For example, the City of Altamonte

Figure 3-17. Anticipated Daily Reclaimed Water Demand Curve vs. Diurnal Reclaimed Water Flow Curve



Springs, Florida, maintains ground storage facilities at the reclamation plant and elevated storage tanks out in the reclaimed water system. Large sites, such as golf courses, commonly have onsite ponds capable of receiving water throughout the day. Such onsite facilities reduce operational storage requirements that need to be provided by the utility. In the City of Naples, Florida where reclaimed water is provided to 9 golf courses, remote booster pump stations deliver reclaimed water to users from a covered storage tank located at the reclamation plant.

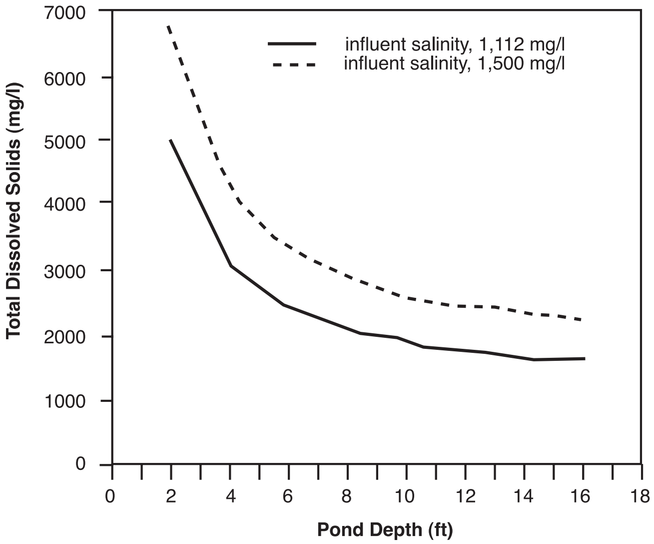
Operational storage facilities are generally covered tanks or open ponds. Covered storage in ground or elevated tanks is used for unrestricted urban reuse where aesthetic considerations are important. Ponds are less costly, in most cases, but generally require more land per gallon stored. Where property costs are high or sufficient property is not available, ponds may not be feasible. Open ponds also result in water quality degradation from biological growth, and chlorine residual is difficult to maintain. Ponds are appropriate for onsite applications such as agricultural and golf course irrigation. In general, ponds that are already being used as a source for irrigation are also appropriate for reclaimed water storage. In addition to the biological aspects of storing reclaimed water in onsite impoundments, the concentration of various constituents due to surface evaporation may present a problem. Reclaimed water often has a more elevated concentration of TDS than other available sources of water. Where evaporation rates are high and rainfall is low, the configuration of onsite storage ponds was found to have significant impacts on water quality in terms of TDS (Chapman and French, 1991). Shallow ponds with a high area-to-volume ratio experience greater concentrations of dissolved solids due to surface evaporation. Dissolved solids increase in all ponds, but deeper ponds can mitigate the problem. **Figure 3-18** summarizes the expected concentration levels of TDS with varying pond depth for reclaimed water with an influent concentration of 1,112 and 1,500 mg/l of TDS, assuming water is lost from storage through evaporation only.

3.6.3 Alternative Disposal Facilities

Beneficial water reclamation and reuse can effectively augment existing water supplies and reduce the water quality impacts of effluent discharge. Yet 100 percent reuse of the effluent may not always be feasible. In such cases, some form of alternative use or disposal of the excess water is necessary. For the purposes of this section, the discharge of reclaimed water will be considered “disposal,” regardless of whether it is for subsequent reuse or permanent disposal.

Where reclamation programs incorporate existing wastewater treatment facilities, an existing disposal system will likely be in place and can continue to be used for partial or intermittent disposal. Common alternative disposal systems include surface water discharge, injection wells, land application, and wetlands application.

Figure 3-18. TDS Increase Due to Evaporation for One Year as a Function of Pond Depth



These methods are described below.

3.6.3.1 Surface Water Discharge

Intermittent surface water discharge may provide an acceptable method for the periodic disposal of excess reclaimed water. While demand for reclaimed water normally declines during wet weather periods, it is during wet weather periods that surface waters are generally more able to assimilate the nutrients in reclaimed water without adverse water quality impacts. Conversely, during the warm summer months when surface water bodies are often most susceptible to the water quality impacts of effluent discharges, the demand for irrigation water is high and an excess of reclaimed water is less likely. Thus, the development of a water reuse program with intermittent discharges can reduce or eliminate wastewater discharges during periods when waters are most sensitive to nutrient concentrations while allowing for discharges at times when adverse impacts are less likely. By eliminating discharges for a portion of the year through water reuse, a municipality may also be able to avoid the need for costly advanced wastewater treatment nutrient removal processes often required for a continuous discharge. The New York City's investigation into water reclamation included a comparison of the reduction in nitrogen loadings that could be achieved through BNR treatment or beneficial reuse. **Table 3-15** provides a summary of this effort and indicates the volume of water that must be diverted to reuse in order to equal the nutrient reduction that would be realized from a given level of BNR treatment.

In the City of Petaluma, California the ability to protect the downstream habitat by eliminating surface water discharges from May through September played a major role in considering reuse. (Putnam, 2002).

3.6.3.2 Injection Wells

Injection wells, which convey reclaimed water into subsurface formations, are also used as an alternative means of disposal, including eventual reuse via groundwater recharge. Thus, the purpose of the disposal (permanent or for future reuse) will typically determine the type and regulatory framework of the injection wells. The EPA Underground Injection Control (UIC) program has categorized injection wells into 5 classes, only 2 of which (Class I and V) apply to reclaimed water disposal.

Class I injection wells are technologically sophisticated and inject hazardous and non-hazardous wastes below the lowermost underground source of drinking water (USDW). Injection occurs into deep, isolated rock formations that are separated from the lowermost USDW by layers of impermeable clay and rock. In general, owners and operators of most new Class I injection wells are required to:

- Site the injection wells in a location that is free of faults and other adverse geological features. Drill to a depth that allows the injection into formations that do not contain water that can potentially be used as a source of drinking water. These injection zones are confined from any formation that may contain water that may potentially be used as a source of drinking water.

- Inject through an internal pipe (tubing) that is located inside another pipe (casing). This outer pipe has cement on the outside to fill any voids occurring between the outside pipe and the hole that was bored for the well (borehole). This allows for multiple layers of containment of the potentially contaminating injection fluids.

- Test for integrity at the time of completion and every 5 years thereafter (more frequently for hazardous waste wells).

- Monitor continuously to assure the integrity of the well.

Class V injection wells will likely include nearly all reclaimed water injection wells that are not permitted as Class I injection wells. Under the existing federal regulations, Class V injection wells are "authorized by rule" (40 CFR 144), which means they do not require a federal permit if they do not endanger underground sources of drinking water and comply with other UIC program requirements. However, individual states may require specific treatment, well construction, and water quality monitoring standards compliance before permitting any injection of reclaimed water into aquifers that are currently or could potentially be used for potable supply. A discussion about potential reclaimed water indirect potable reuse guidelines is contained in Chapter 4.

Injection wells are a key component of the urban reuse program in the City of St. Petersburg, Florida. The city operates 10 wells, which inject excess reclaimed water into a saltwater aquifer at depths between 700 and 1,000 feet (210 and 300 meters) below the land surface. Approximately 50 percent of the available reclaimed water is disposed of through injection. When originally installed, the wells were permitted as Class I injection wells with the primary use for the management of excess reclaimed water, but also were employed to dispose of any reclaimed water not meeting water quality standards. The City is in the permitting process to convert the wells to Class V injection wells, for primary use as an ASR system.

Under suitable circumstances, excess reclaimed water can be stored in aquifers for subsequent reuse. In Orange County, California injection of reclaimed water into potable supply aquifers has been conducted for seawater intrusion control and groundwater recharge since 1976 and has expanded in recent years to Los Angeles County, California. New advanced water treatment and injection projects are underway in both counties to supply the majority of coastal injection wells in Orange and Los Angeles counties with reclaimed water to reduce dependence on imported water from the Colorado River and northern California. Additional discussion about reclaimed water recharge can be found in Chapter 2.

3.6.3.3 Land Application

In water reuse irrigation systems, reclaimed water is applied in quantities to meet an existing water demand. In land treatment systems, effluent may be applied in excess of the needs of the crop. Land application systems can provide reuse benefits, such as irrigation and/or groundwater recharge. However, in many cases, the main focus of land application systems is to avoid detrimental impacts to groundwater that can result from the application of nutrients or toxic compounds.

In some cases, a site may be amenable to both reuse and "land application". Such are the conditions of a Tallahassee, Florida sprayfield system. This system is located on a sand ridge, where only drought-tolerant flora can survive without irrigation. By providing reclaimed water for irrigation, the site became suitable for agricultural production of multiple crop types. However, because of the extreme infiltration and percolation rates, it is possible to apply up to 3 inches per week (8 cm per week) of reclaimed water without significant detrimental impacts to the crop (Allhands and Overman, 1989).

The use of land application as an alternative means of disposal is subject to hydrogeological considerations. The EPA manual *Land Treatment of Municipal Wastewater* (U.S. EPA, 1981) provides a complete discussion of the design requirements for such systems.

The use of land application systems for wet weather disposal is limited unless high infiltration and percolation rates can be achieved. This can be accomplished through the use of rapid infiltration basins or manmade wetlands.

In cases where manmade wetlands are created, damaged wetlands are restored, or existing wetlands are en-

Table 3-15. Nitrogen Mass Removal Strategies: Nutrient Removal vs. Water Reuse

Water Pollution Control Facility	1998 Total Flow (mgd)	1998 Effluent TN (lbs/d)	Step Feed BNR Projected TN Discharge (lbs/d)	Equivalent Water Reuse (mgd)	Enhanced Step Feed BNR & Separate Centrate Treatment (lbs/d)	Equivalent Water Reuse (mgd)
Wards Island	224	29,000	24,000	39	12,500	128
Hunts Point	134	19,000	16,000	22	9,500	67
Tallman Island	59	7,700	3,500	33	3,500	33
Bowery Bay	126	19,700	11,000	56	6,500	85
26th Ward	69	15,500	7,500	36	5,000	48

hanced, wetlands application may be considered a form of water reuse, as discussed in Section 2.5.1. Partial or intermittent discharges to wetlands systems have also been incorporated as alternative disposal means in water reuse systems, with the wetlands providing additional treatment through filtration and nutrient uptake.

A wetlands discharge is used in Orange County, Florida, where a portion of the reclaimed water generated by the Eastern Service Area WWTF is reused for power plant cooling, and the remainder is discharged by overland flow to a system of manmade and natural wetlands. **Figure 3-19** shows the redistribution construction wetlands system. Application rates are managed to simulate natural hydroperiods of the wetland systems (Schanze and Voss, 1989).

3.7 Environmental Impacts

Elimination or reduction of a surface water discharge by reclamation and reuse generally reduces adverse water quality impacts to the receiving water. However, moving the discharge from a disposal site to a reuse system may have secondary environmental impacts. An environmental assessment may be required to meet state or local regulations and is required whenever federal funds are used. Development of water reuse systems may have unintended environmental impacts related to land use, stream flow, and groundwater quality. Formal guidelines for the development of an environmental impact statement (EIS) have been established by the EPA. Such studies are generally associated with projects receiving federal funding or new NPDES permits and are not specifically associated with reuse programs. Where an investigation of environmental impacts is required, it may be subject to state policies.

Figure 3-19. Orange County, Florida, Redistribution Constructed Wetland

The following conditions are given as those that would induce an EIS in a federally-funded project:

- The project may significantly alter land use.
- The project is in conflict with any land use plans or policies.
- Wetlands will be adversely impacted.
- Endangered species or their habitat will be affected.
- The project is expected to displace populations or alter existing residential areas.
- The project may adversely affect a flood plain or important farmlands.
- The project may adversely affect parklands, preserves, or other public lands designated to be of scenic, recreational, archaeological, or historical value.
- The project may have a significant adverse impact upon ambient air quality, noise levels, surface or groundwater quality or quantity.
- The project may have adverse impacts on water supply, fish, shellfish, wildlife, and their actual habitats.

The types of activities associated with federal EIS requirements are outlined below. Many of the same requirements are incorporated into environmental assessments required under state laws.

3.7.1 Land Use Impacts

Water reuse can induce significant land use changes, either directly or indirectly. Direct changes include shifts in vegetation or ecosystem characteristics induced by alterations in water balance in an area. Indirect changes include land use alterations associated with industrial, residential, or other development made possible by the added supply of water from reuse. Two cases from Florida illustrate this point.

- A study in the Palm Beach County, Florida area determined that reuse could provide water supply sufficient to directly and substantially change the hydroperiod in the area. This change was significant enough to materially improve the potential for sustaining a wetlands ecosystem and for controlling the extent and spread of invasive species. In short, the added reuse water directly affected the nature of land cover in the area.

- Indirect changes were also experienced in agricultural land use in the Orange County, Florida area. Agricultural use patterns were found to be materially influenced by water reuse associated with the Water Conserv II project. Commercial orange groves were sustained and aided in recovery from frost damage to crops by the plentiful supply of affordable water generated by reuse. The added reuse water affected the viability of agriculture, and therefore, indirectly affected land use in the area.

Other examples of changes in land use as a result of available reuse water include the potential for urban or industrial development in areas where natural water availability limits the potential for growth. For example, if the supply of potable water can be increased through recharge using reuse supply, then restrictions to development might be reduced or eliminated. Even nonpotable supplies, made available for uses such as residential irrigation, can affect the character and desirability of developed land in an area. Similar effects can also happen on a larger scale, as municipalities in areas where development options are constrained by water supply might find that nonpotable reuse enables the development of parks or other amenities that were previously considered to be too costly or difficult to implement. Commercial users such as golf courses, garden parks, or plant nurseries have similar potential for development given the presence of reuse supplies.

The potential interactions associated with land use changes are complex, and in some cases the conclusion that impacts are beneficial is subjective. An increase in urban land use, for example, is not universally viewed as a positive change. For this reason, the decision-making process involved in implementing a reclamation program should result from a careful consideration of stakeholder goals.

3.7.2 Stream Flow Impacts

Instream flows can either increase or decrease as a consequence of reuse projects. In each situation where reuse is considered, there is the potential to shift water balances and effectively alter the prevailing hydrologic regime in an area. Two examples of the way flows can increase as a result of a reuse project are as follows:

- In streams where dry weather base flows are groundwater dependant, land application of reclaimed water for irrigation or other purposes can cause an increase in base flows, if the prevailing groundwater elevation is raised. (Groundwater effects are discussed further in Section 3.7.3.)
- Increases in stream flows during wet periods can result from reduced soil moisture capacity in a tributary watershed, if there is pervasive use of recharge on the land surface during dry periods. In such a case, antecedent conditions are wetter, and runoff greater, for a given rainstorm. The instream system bears the consequences of this change.

It is important to note that the concurrent effects of land use changes discussed in Section 3.7.1 can exacerbate either of the above effects.

Instream flow reduction is also possible, and can be more directly evident. For example, the Trinity River in Texas, in the reaches near the City of Dallas, maintains a continuous flow of several hundred cubic feet per second during dry periods. This flow is almost entirely composed of treated effluent from discharges further upstream. If extensive reuse programs were to be implemented at the upstream facilities, dry weather flows in this river would be jeopardized and plans for urban development downstream could be severely impacted due to lack of available water.

In addition to water quantity issues, reuse programs can potentially impact aesthetics or recreational use and damage ecosystems associated with streams where hydrologic behavior is significantly affected. Where wastewater discharges have occurred over an extended period of time, the flora and fauna can adapt and even become dependent on that water. A new or altered ecosystem can arise, and a reuse program implemented without consideration of this fact could have an adverse impact on such a community. In some cases, water reuse projects have been directly affected by concerns for instream flow reduction that could result from a reuse program. The San Antonio Water System (SAWS) in Texas defined the historic spring flow at the San Antonio River headwaters during development of their reclaimed water system. In cooperation with downstream users and the San Antonio River Authority, SAWS agreed to maintain a release of 55,000 acre-feet per year (68 x 10^6 m^3 per year) from its water reclamation facilities. This policy protects and enhances downstream water quality and provides 35,000 acre-feet per year (43 x 10^6 m^3 per year) of reclaimed water for local use.

In the State of Washington, reuse water can be discharged to a stream as stream flow augmentation. Under this provision, reclaimed water can be discharged to surface water for purposeful uses such as:

- If the flow is to maintain adequate flows for aquatic life
- If the reclaimed water is going to be used downstream and therefore the stream is acting as a conduit

In the City of Sequim, Washington 0.1 cfs (2.8 l/s) of reclaimed water is discharged into the Bell Stream to keep the benthic layer wet. The flow is not intended to maintain an environment for fish, but instead to maintain other small species that live in the streambed. To date, no studies have been conducted to show the effects to the ecosystem.

The implication of these considerations is that a careful analysis of the entire hydrologic system is an appropriate consideration in a reuse project if instream impacts are to be understood. This is particularly the case when the magnitude of the flows impacted by the reuse program is large, relative to the quantities involved in the hydrologic system that will be directly impacted by the reuse program.

3.7.3 Hydrogeological Impacts

As a final environmental consideration of water reuse, the groundwater quality effects of the reclaimed water for the intended use must be reviewed. The exact concerns of any project are evaluated on a case-by-case basis. One of the better-known sources of potential groundwater pollution is nitrate, which may be found in, or result from, the application of reclaimed water. However, additional physical, chemical, and biological constituents found in reclaimed water may pose an environmental risk. In general, these concerns increase when there are significant industrial wastewater discharges to the water reclamation facility.

Impacts of these constituents are influenced by the hydrogeology of the reuse application site. Where karst conditions exist, for example, constituents may potentially exist within the reclaimed water that will ultimately reach the aquifer. In many reclaimed water irrigation programs, a groundwater-monitoring program is required to detect the impacts of reclaimed water constituents.

3.8 Case Studies

3.8.1 Code of Good Practices for Water Reuse

The Florida Department of Environmental Protection (FDEP) and the Florida Water Environment Association's (FWEA) Water Reuse committee have developed the Code of Good Practices for Water Reuse in Florida (FDEP, 2002). The Code of Good Practices includes 16 principles and is designed to aid reuse utilities as they implement quality water reuse programs.

Protection of Public Health and Environmental Quality

Public Health Significance – To recognize that distribution of reclaimed water for nonpotable purposes offers potential for public contact and that such contact has significance related to the public health.

Compliance – To comply with all applicable state, federal, and local requirements for water reclamation, storage, transmission, distribution, and reuse of reclaimed water.

Product – To provide reclaimed water that meets state treatment and disinfection requirements and that is safe and acceptable for the intended uses when delivered to the end users.

Quality Monitoring and Process Control – To continuously monitor the reclaimed water being produced and rigorously enforce the approved operating protocol such that only high-quality reclaimed water is delivered to the end users.

Effective Filtration – To optimize performance of the filtration process in order to maximize the effectiveness of the disinfection process in the inactivation of viruses and to effectively remove protozoan pathogens.

Cross-Connection Control – To ensure that effective cross-connection control programs are rigorously enforced in areas served with reclaimed water.

Inspections – To provide thorough, routine inspections of reclaimed water facilities, including facilities located on the property of end users, to ensure that reclaimed water is used in accordance with state and local requirements and that cross-connections do not occur.

Reuse System Management

Water Supply Philosophy – To adopt a “water supply” philosophy oriented towards reliable delivery of a high-quality reclaimed water product to the end users.

Conservation – To recognize that reclaimed water is a valuable water resource, which should be used efficiently and effectively to promote conservation of the resource.

Partnerships – To enter into partnerships with the Department of Environmental Protection, the end users, the public, the drinking water utility, other local and regional agencies, the water management district, and the county health department to follow and promote these practices.

Communications – To provide effective and open communication with the public, end users, the drinking water utility, other local and regional agencies, the Department of Environmental Protection, the water management district, and the county health department.

Contingency Plans – To develop response plans for unanticipated events, such as inclement weather, hurricanes, tornadoes, floods, drought, supply shortfalls, equipment failure, and power disruptions.

Preventative Maintenance – To prepare and implement a plan for preventative maintenance for equipment and facilities to treat wastewater and to store, convey, and distribute reclaimed water.

Continual Improvement – To continually improve all aspects of water reclamation and reuse.

Public Awareness

Public Notification – To provide effective signage advising the public about the use of reclaimed water and to provide effective written notification to end users of reclaimed water about the origin of, the nature of, and proper use of reclaimed water.

Education – To educate the public, children, and other agencies about the need for water conservation and reuse, reuse activities in the state and local area, and environmentally sound wastewater management and water reuse practices.

3.8.2 Examples of Potable Water Separation Standards from the State of Washington

Efforts to control cross-connections invariably increase as part of the implementation of dual distribution systems involving potable and nonpotable lines. A fundamental element of these cross-connection control elements is the maintenance of a separation between potable and nonpotable pipelines. While the specific requirements often vary from state to state, common elements typically include color-coding requirements as well as minimum vertical and horizontal separations. Excerpts from the State of Washington, “Reclaimed Water – Potable Water Separation Standards,” are provided below as an example of these requirements.

Policy Requirements: Potable water lines require protection from any nonpotable water supply, including all classes of reclaimed water. For buried pipelines, proper pipe separation must be provided.

General Requirements: Standard potable-nonpotable pipe separation standards should be observed at:

1. Parallel Installations: Minimum horizontal separation of 10 feet (3 meters) pipe-to-pipe.
2. Pipe Crossings: Minimum vertical separation of 18 inches (0.5 meters) pipe-to-pipe, with potable lines crossing above nonpotable.

Special Conditions: Special laying conditions where the required separations cannot be maintained may be addressed as shown in the following examples.

Figure 3-20. A Minimum 5-foot (1.5-meter) Horizontal Pipe Separation Coupled with an 18-inch (46-cm) Vertical Separation

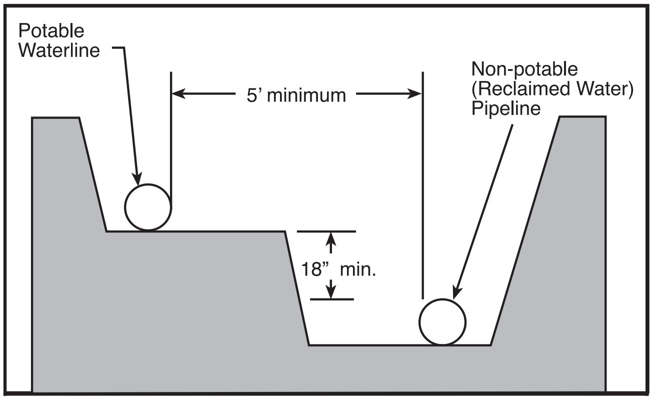
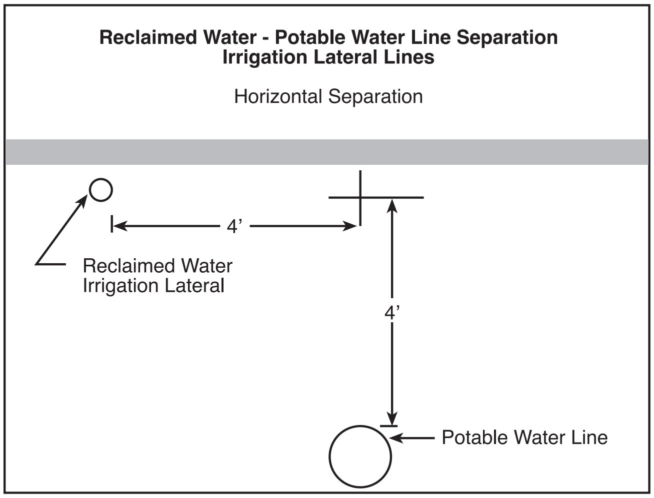


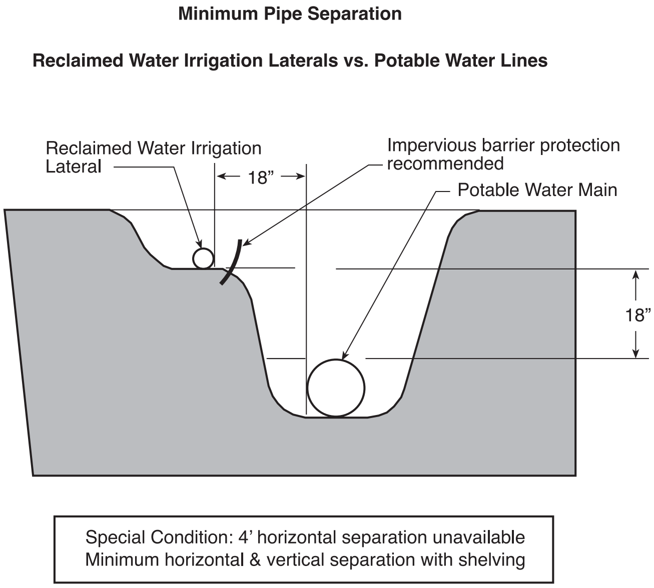
Figure 3-21. Irrigation Lateral Separation



Pipeline Separation: Minimum pipeline separation between any potable water line and reclaimed water irrigation laterals shall be 48 inches (1.2 meters) pipe-to-pipe separation.

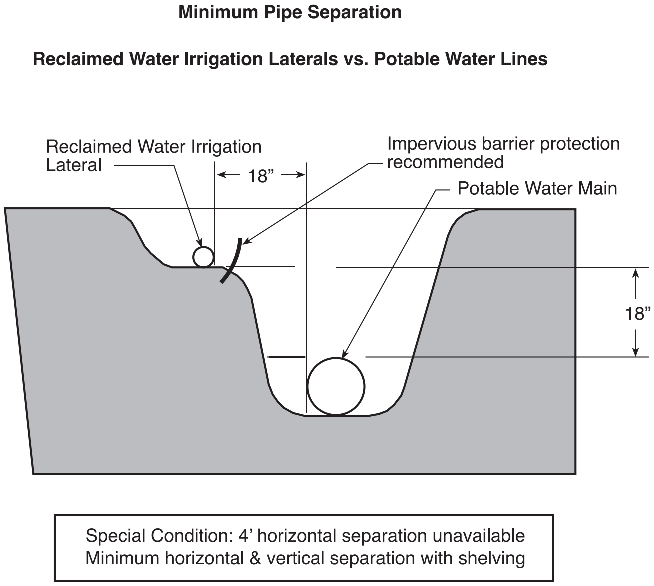
Special Condition Number 1- Irrigation Lateral Crossings: Reclaimed water irrigation laterals will commonly cross above potable water lines due to normal depths of bury. To provide adequate protection, the reclaimed water irrigation lateral shall be cased in pressure-rated pipe to a minimum distance of 4 feet (1.2 meters) on each side of the potable water line.

Figure 3-22. Lateral Crossing Requirements



Special Condition Number 2 - Inadequate Horizontal Separation: Site limitations will likely result in parallel pipe installations with less than 48 inches (1.2 meters) of pipe-to-pipe separation. In these instances, a minimum pipe-to-pipe separation of 18 inches (46 cm) shall be provided, and the reclaimed water irrigation lateral shall be installed a minimum of 18 inches (46 cm) above the potable water pipeline. An impervious barrier, such as PVC sheeting, installed between the irrigation lateral and the waterline for the length of the run is recommended.

Figure 3-23. Parallel Water - Lateral Installation



3.8.3 An Example of Using Risk Assessment to Establish Reclaimed Water Quality

Historically, the microbiological quality of both wastewater effluents and reclaimed water has been based on indicator organisms. This practice has proved to be effective and will likely continue into the foreseeable future.

However, given uncertainties in the use of indicator organisms to control pathogens in reclaimed water and in other waters, regulatory agencies could consider developing a number of guidelines or standards for selected pathogens using microbiological risk assessment. Development of risk-based guidelines or standards could include:

1. Selection of appropriate pathogens
2. Selection of microbial risk models
3. Structuring of exposure scenarios

4. Selection of acceptable risk levels

5. Calculation of the concentration of the pathogen that would result in a risk equal to the acceptable level of risk

As an example, York and Walker-Coleman (York and Walker-Coleman, 1999, 2000) used a risk assessment approach to evaluate guidelines for nonpotable reuse activities. These investigations developed guidelines for *Giardia, Cryptosporidium*, and enteroviruses using the following models:

Organism	Model Used	Parameters
Echovirus 12 (moderately infective)	$P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-Poisson)	$\alpha = 0.374$ $\beta = 186.7$
Rotavirus (highly infective)	$P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-Poisson)	$\alpha = 0.26$ $\beta = 0.42$
Cryptosporidium	$P_i = 1 – e^{-rN}$ (exponential)	r = 0.00467
Giardia	$P_i = 1 – e^{-rN}$ (exponential)	r = 0.0198

Source: Rose and Carnahan, 1992, Rose *et al.,* 1996

Since specific types of viruses typically are not quantified when assessing viruses in reclaimed water, assumptions about the type of viruses present were required. For the purpose of developing a risk assessment model, it was assumed that all viruses would be highly infective rotaviruses. Helminths were not evaluated, since data from St. Petersburg, Florida showed that helminths were consistently removed in the secondary clarifiers of a water reclamation facility (Rose and Carnahan, 1992, Rose *et al.*, 1996).

In this analysis, an annual risk of infection of 1×10^{-4} was used as the “acceptable level of risk.” Two exposure scenarios were evaluated. Average conditions were evaluated based on the assumption that an individual would ingest 1.0 ml of reclaimed water (or its residue) on each of 365 days during the year. In addition, a worst-case scenario involving ingestion of 100 ml of reclaimed water on a single day during the year was evaluated. These exposure scenarios were judged representative of the use of reclaimed water to irrigate a residential lawn. The exposure scenarios could be adjusted to fit other reuse activities, such as irrigation of a golf course, park, or school. The results of this exercise are summarized in **Table 3-16.**

It is important to note that, particularly for the protozoan pathogens, the calculations assume that all pathogens present in reclaimed water are intact, viable, and fully capable of causing infection. A *Giardia* infectivity study conducted by the Los Angeles County Sanitation District (Garcia *et al.*, 2002) demonstrated that *Giardia* cysts passing through a water reclamation facility were not infectious. This basic approach could be applied to other waters and could be used to establish consistency among the various water programs.

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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Table 3-16. Average and Maximum Conditions for Exposure

Organism	Units	Calculated Allowable Concentrations	
		Average	Maximum
Giardia	Viable, infectious cysts/100 l	1.4	5
Cryptosporidium	Viable, infectious oocysts/100 l	5.8	22
Enterovirus (a)	PFU/100 l	0.044	0.165

Note: (a) Assumes all viruses are highly infective Rotavirus.
Source: York and Walker-Coleman, 1999, 2000

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CHAPTER 4

Water Reuse Regulations and Guidelines in the U.S.

Most reuse programs operate within a framework of regulations that must be addressed in the earliest stages of planning. A thorough understanding of all applicable regulations is required to plan the most effective design and operation of a water reuse program and to streamline implementation.

Regulations refer to actual rules that have been enacted and are enforceable by government agencies. Guidelines, on the other hand, are not enforceable but can be used in the development of a reuse program. Currently, there are no federal regulations directly governing water reuse practices in the U.S. Water reuse regulations and guidelines have, however, been developed by many individual states. As of November 2002, 25 states had adopted regulations regarding the reuse of reclaimed water, 16 states had guidelines or design standards, and 9 states had no regulations or guidelines. In states with no specific regulations or guidelines on water reclamation and reuse, programs may still be permitted on a case-by-case basis.

Regulations and guidelines vary considerably from state to state. States such as Arizona, California, Colorado, Florida, Georgia, Hawaii, Massachusetts, Nevada, New Jersey, New Mexico, North Carolina, Ohio, Oregon, Texas, Utah, Washington, and Wyoming have developed regulations or guidelines that strongly encourage water reuse as a water resources conservation strategy. These states have developed comprehensive regulations or guidelines specifying water quality requirements, treatment processes, or both, for the full spectrum of reuse applications. The objective in these states is to derive the maximum resource benefits of the reclaimed water while protecting the environment and public health. Other states have developed water reuse regulations with the primary intent of providing a disposal alternative to discharge to surface waters, without considering the management of reclaimed water as a resource.

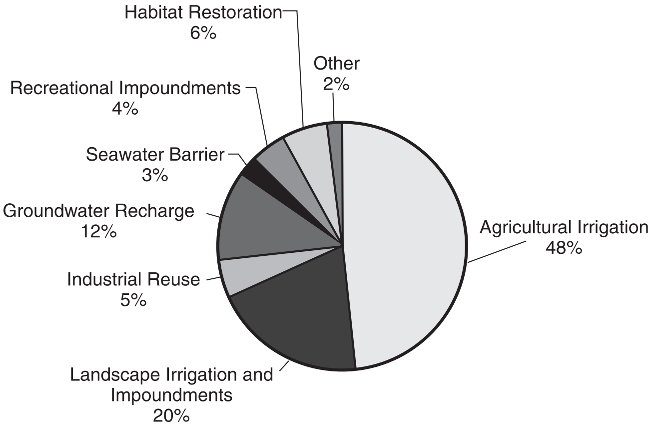
This section provides an inventory of the various state water reuse regulations throughout the U.S. and updates recommended guidelines that may aid in the development of more comprehensive state or even federal standards for water reuse. Water reuse outside the U.S. is discussed in Chapter 8.

4.1 Inventory of Existing State Regulations and Guidelines

The following inventory of state reuse regulations and guidelines is based on a survey of all states conducted specifically for this document. Regulatory agencies in all 50 states were contacted and information was obtained concerning their regulations governing water reuse. All of the information presented in this section is considered current as of November 2002.

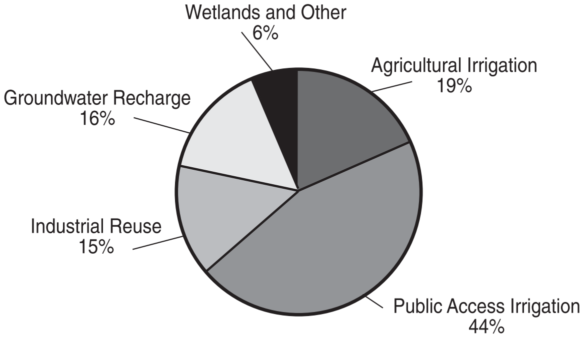
California and Florida compile comprehensive inventories of reuse projects by type of reuse application. These inventories are compiled by the California Water Resources Control Board (CWRCB) in Sacramento and the Florida Department of Environmental Protection (FDEP) in Tallahassee, respectively. The inventories are available for viewing or downloading from each agency's website. Florida's 2001 Reuse Inventory shows a total of 461 domestic wastewater treatment facilities with permitted capacities of 0.1 mgd (4.4 l/s) or more that produce reclaimed water. These treatment facilities serve 431 reuse systems and provide 584 mgd (25,600 l/s) of reclaimed water for beneficial purposes. The total reuse capacity associated with these systems is 1,151 mgd (50,400 l/s) (FDEP, 2002). California's May 2000 Municipal Wastewater Reclamation Survey, estimated a total of 358 mgd (14,800 l/s) treated municipal wastewater was being reused. This represents a 50 percent increase from the survey undertaken by CWRCB in 1987. The wastewater is treated at 234 treatment plants and is being reused at approximately 4,840 sites (CWRCB, 2000). **Figures 4-1 and 4-2** show the types of reuse occurring in California and Florida, respectively.

Figure 4-1. California Water Reuse by Type (Total 358 mgd)



Source: Adapted from California Environmental Protection Agency

Figure 4-2. Florida Water Reuse by Type (Total 584 mgd)



Source: 2001 Florida Water Reuse Inventory

Every 5 years, the U.S. Geological Survey (USGS) compiles an estimate of national reclaimed water use that is entered in a national database system and publishes its findings in a national circular, *Estimated Use of Water in the United States.* The 1995 publication estimated that approximately 983 mgd (43,060 l/s) of the effluent discharged in the U.S. was released for beneficial reuse, an increase of 55 mgd (2,410 l/s) from the 1990 estimate (Perlman *et al.,* 1998). More current estimates were not available from the USGS at the time of this update, but it is anticipated that the 2000 publication will be available at the time these guidelines are published.

Most states do not have regulations that cover all potential uses of reclaimed water. Arizona, California, Colorado, Florida, Hawaii, Nevada, New Jersey, Oregon, Texas, Utah, and Washington have extensive regulations or guidelines that prescribe requirements for a wide range of end uses of the reclaimed water. Other states have regulations or guidelines that focus upon land treatment of wastewater effluent, emphasizing additional treatment or effluent disposal rather than beneficial reuse, even though the effluent may be used for irrigation of agricultural sites, golf courses, or public access lands.

Based on the inventory, current regulations and guidelines may be divided into the following reuse categories:

- Unrestricted urban reuse – irrigation of areas in which public access is not restricted, such as parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments.
- Restricted urban reuse – irrigation of areas in which public access can be controlled, such as golf courses, cemeteries, and highway medians.
- Agricultural reuse on food crops – irrigation of food crops which are intended for direct human consumption, often further classified as to whether the food crop is to be processed or consumed raw.
- Agricultural reuse on non-food crops – irrigation of fodder, fiber, and seed crops, pasture land, commercial nurseries, and sod farms.
- Unrestricted recreational reuse – an impoundment of water in which no limitations are imposed on body-contact water recreation activities.
- Restricted recreational reuse – an impoundment of reclaimed water in which recreation is limited to fishing, boating, and other non-contact recreational activities.
- Environmental reuse – reclaimed water used to create manmade wetlands, enhance natural wetlands, and sustain or augment stream flows.
- Industrial reuse – reclaimed water used in industrial facilities primarily for cooling system make-up water, boiler-feed water, process water, and general washdown.

- Groundwater recharge – using either infiltration basins, percolation ponds, or injection wells to recharge aquifers.

- Indirect potable reuse – the intentional discharge of highly treated reclaimed water into surface waters or groundwater that are or will be used as a source of potable water.

Table 4-1 (on the following page) provides an overview of the current water reuse regulations and guidelines by state and by reuse category. The table identifies those states that have regulations, those with guidelines, and those states that currently do not have either. Regulations refer to actual rules that have been enacted and are enforceable by government agencies. Guidelines, on the other hand, are not enforceable but can be used in the development of a reuse program.

The majority of current state regulations and guidelines pertain to the use of reclaimed water for urban and agricultural irrigation. At the time of the survey, the only states that had specific regulations or guidelines regarding the use of reclaimed water for purposes other than irrigation were Arizona, California, Colorado, Florida, Hawaii, Massachusetts, Nevada, New Jersey, North Carolina, Oregon, South Dakota, Texas, Utah, and Washington. The 1995 Substitute Senate Bill 5605, "Reclaimed Water Act," passed in the State of Washington, states that reclaimed water is no longer considered wastewater (Van Riper *et al.,* 1998).

Table 4-2 shows the number of states with regulations or guidelines for each type of reuse. The category of unrestricted urban reuse has been subdivided to indicate the number of states that have regulations pertaining to urban reuse not involving irrigation.

States with regulations or guidelines pertaining to the use of reclaimed water for the following unrestricted urban reuse categories are:

- Toilet Flushing – Arizona, California, Florida, Hawaii, Massachusetts, New Jersey, North Carolina, Texas, Utah, and Washington

- Fire Protection – Arizona, California, Florida, Hawaii, New Jersey, North Carolina, Texas, Utah, and Washington

- Construction Purposes – Arizona, California, Florida, Hawaii, New Jersey, North Carolina, Oregon, Utah, and Washington

- Landscape or Aesthetic Impoundments – Arizona, California, Colorado, Florida, Hawaii, Nevada, New Jersey, North Carolina, Oregon, Texas, and Washington

- Street Cleaning – Arizona, California, Florida, Hawaii, North Carolina, and Washington

Table 4-2. **Number of States with Regulations or Guidelines for Each Type of Reuse Application**

Type of Reuse	Number of States
Unrestricted Urban	28
Irrigation	28
Toilet Flushing	10
Fire Protection	9
Construction	9
Landscape Impoundment	11
Street Cleaning	6
Restricted Urban	34
Agricultural (Food Crops)	21
Agricultural (Non-food Crops)	40
Unrestricted Recreational	7
Restricted Recreational	9
Environmental (Wetlands)	3
Industrial	9
Groundwater Recharge (Nonpotable Aquifer)	5
Indirect Potable Reuse	5

Table 4-1. Summary of State Reuse Regulations and Guidelines

State	Regulations	Guidelines	No Regulations or Guidelines (1)	Change from 1992 Guidelines for Water Reuse (2)	Unrestricted Urban Reuse	Restricted Urban Reuse	Agricultural Reuse Food Crops	Agricultural Reuse Non-Food Crops	Unrestricted Recreational Reuse	Restricted Recreational Reuse	Environmental Reuse	Industrial Reuse	Groundwater Recharge	Indirect Potable Reuse
Alabama		●		N		●		●						
Alaska	●			NR				●						
Arizona	●			U	●	●	●	●		●				
Arkansas		●		N	●	●	●	●						
California (3)	●			U	●	●	●	●	●	●		●	●	●
Colorado	● (4)			GR	●	●	●	●	●	●				
Connecticut			●	N										
Delaware	●			GR	●	●		●						
Florida	●			U	●	●	●	●			●	●	●	●
Georgia		●		U	●	●		●						
Hawaii		●		U	●	●	●	●		●		●	●	●
Idaho	●			N	●	●	●	●						
Illinois	●			U	●	●		●						
Indiana	●			U	●	●	●	●						
Iowa	●			NR		●		●						
Kansas		●		N	●	●	●	●						
Kentucky			●	N										
Louisiana			●	N										
Maine			●	N										
Maryland		●		N		●		●						
Massachusetts		●		NG	●	●		●					●	●
Michigan	●			N			●	●						
Minnesota			●	N										
Mississippi			●	N										
Missouri	●			N		●		●						
Montana	●			GR	●	●	●	●						
Nebraska	●			GR		●		●						
Nevada	●			GR	●	●	●	●	●	●				
New Hampshire			●	N										
New Jersey		●		RG	●	●	●	●				●		
New Mexico		●		N	●	●	●	●						
New York		●		N				●						
North Carolina	●			U	●	●						●		
North Dakota		●		U	●	●		●						
Ohio		●		NG	●	●		●						
Oklahoma	●			GR		●	●	●						
Oregon	●			N	●	●	●	●	●	●		●		
Pennsylvania		●		NG				●						
Rhode Island			●	N										
South Carolina	●			GR	●	●		●						
South Dakota		●		N	●	●		●			●			
Tennessee	●			N	●	●		●						
Texas	●			U	●	●	●	●	●	●		●		
Utah	●			U	●	●	●	●	●	●		●		
Vermont	●			N				●						
Virginia			●	N										
Washington		●		U	●	●	●	●	●	●	●	●	●	●
West Virginia	●			N			●	●						
Wisconsin	●			N				●						
Wyoming	●			U	●	●	●	●						

(1) Specific regulations on reuse not adopted: however, reclamation may be approved on a case-by-case basis

(2)
N - no change
NR - no guidelines or regulations to regulations
U - updated guidelines or regulations
NG - no guidelines or regulations to guidelines
GR - guidelines to regulations
RG - regulations to guidelines

(3) Has regulations for landscape irrigation excluding residential irrigation; guidelines cover all other uses

It is important to understand that because a state does not have specific guidelines or regulations for a particular type of reuse as defined in this chapter, it does not mean that the state does not allow that type of reuse under other uses. Also, some states allow consideration of reuse options that are not addressed within their existing guidelines or regulations. For example, Florida's rules governing water reuse enable the state to permit other uses, if the applicant demonstrates that public health will be protected.

4.1.1 Reclaimed Water Quality and Treatment Requirements

Requirements for water quality and treatment receive the most attention in state reuse regulations. States that have water reuse regulations or guidelines have set standards for reclaimed water quality and/or specified minimum treatment requirements. Generally, where unrestricted public exposure is likely in the reuse application, wastewater must be treated to a high degree prior to its application. Where exposure is not likely, however, a lower level of treatment is usually accepted. The most common parameters for which water quality limits are imposed are biochemical oxygen demand (BOD), total suspended solids (TSS), and total or fecal coliform counts. Total and fecal coliform counts are generally used as indicators to determine the degree of disinfection. A limit on turbidity is usually specified to monitor the performance of the treatment facility.

This discussion on reclaimed water quality and treatment requirements is based on the regulations from the following states: Arizona, California, Florida, Hawaii, Nevada, Texas, and Washington. These regulations were chosen because these states provide a collective wisdom of successful reuse programs and long-term experience.

4.1.1.1 Unrestricted Urban Reuse

Unrestricted urban reuse involves the use of reclaimed water where public exposure is likely in the reuse application, thereby necessitating a high degree of treatment. In general, all states that specify a treatment process require a minimum of secondary treatment and treatment with disinfection prior to unrestricted urban reuse. However, the majority of states require additional levels of treatment that may include oxidation, coagulation, and filtration. Texas does not specify the type of treatment processes required and only sets limits on the reclaimed water quality. **Table 4-3** shows the reclaimed water quality and treatment requirements for unrestricted urban reuse.

Where specified, limits on BOD range from 5 mg/l to 30 mg/l. Texas requires that BOD not exceed 5 mg/l (monthly

Table 4-3. Unrestricted Urban Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized, coagulated, filtered, and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5.0 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	**Fecal**	**Total**	**Fecal**	**Fecal**	**Fecal**	**Fecal**	**Total**
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NS - Not specified by state regulations

average) except when reclaimed water is used for landscape impoundments. In that case, BOD is limited to 10 mg/l. Nevada, on the other hand, requires that BOD not exceed 30 mg/l prior to unrestricted urban reuse. Limits on TSS vary from 5 mg/l to 30 mg/l. Florida requires a TSS limit of 5.0 mg/l prior to disinfection and Washington requires that TSS not exceed 30 mg/l.

Average fecal and total coliform limits range from non-detectable to 20/100 ml. Higher single sample fecal and total coliform limits are allowed in several state regulations. Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 ml, while Texas requires that no single fecal coliform count exceed 75/100 ml.

In general and where specified, limits on turbidity range from 2 to 5 NTU. Most of the states require an average turbidity limit of 2 NTU and a not-to-exceed limit of 5 NTU, although Hawaii's guidelines identify a not-to-exceed limit of 2 NTU. Florida requires continuous on-line monitoring of turbidity as an indicator that the TSS limit of 5.0 mg/l is being met. No limit is specified but turbidity setpoints used in Florida generally range from 2 to 2.5 NTU. California specifies different turbidity requirements for wastewater that has been coagulated and passed through natural and undisturbed soils or a bed of filter media, as well as wastewater passed through membranes. For the first, turbidity is not to exceed 5 NTU for more than 5 percent of the time within a 24-hour period and not to exceed 10 NTU at any time. For the latter, turbidity is not to exceed 0.2 NTU more than 5 percent of the time within a 24-hour period and not to exceed 0.5 NTU at any time.

At this time, no states have set limits on certain pathogenic organisms for unrestricted urban reuse. However, Florida does require monitoring of *Giardia* and *Cryptosporidium* with sampling frequency based on treatment plant capacity. For systems less than 1 mgd (44 l/s), sampling is required one time during each 5-year period. For systems equal to or greater than 1 mgd (44 l/s), sampling is required one time during each 2-year period. Samples are to be taken following the disinfection process.

4.1.1.2 Restricted Urban Reuse

Restricted urban reuse involves the use of reclaimed water where public exposure to the reclaimed water is controlled; therefore, treatment requirements may not be as strict as for unrestricted urban reuse. Six states, which regulate both unrestricted and restricted urban reuse, adjusted requirements downward for the restricted category. Florida imposes the same requirements on both unrestricted and restricted urban access reuse. **Table 4-4** shows the reclaimed water quality and treatment requirements for restricted urban reuse.

Table 4-4. Restricted Urban Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment and disinfection	Secondary – 23, oxidized, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	20 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	NS	NS	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
Coliform	**Fecal**	**Total**	**Fecal**	**Fecal**	**Fecal**	**Fecal**	**Total**
	200/100 ml (Avg)	23/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	23/100 ml (Avg)	200/100 ml (Avg)	23/100 ml (Avg)
	800/100 ml (Max)	240/100 ml (Max in 30 days)	25/100 ml (Max)	200/100 ml (Max)	240/100 ml (Max)	800/100 ml (Max)	240/100 ml (Max)

(1) NS - Not specified by state regulations

Table 4-5. **Agricultural Reuse - Food Crops**

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized, coagulated, filtered, and disinfected
BOD5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	**Fecal**	**Total**	**Fecal**	**Fecal**	**Fecal**	**Fecal**	**Total**
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	400/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NS - Not specified by state regulations

In general, the states require a minimum of secondary or biological treatment followed by disinfection prior to restricted urban reuse. Florida requires additional levels of treatment with filtration and possibly coagulation prior to restricted urban reuse. As in unrestricted urban reuse, Texas does not specify the type of treatment processes required and only sets limits on the reclaimed water quality.

Where specified, limits on average BOD range from 20 mg/l to 30 mg/l. Florida and Texas require that BOD not exceed 20 mg/l, while Nevada and Washington require that BOD not exceed 30 mg/l prior to restricted urban reuse. Limits on TSS vary from 5 mg/l to 30 mg/l. Florida requires that TSS not exceed 5.0 mg/l, while Washington requires that TSS not exceed 30 mg/l. As in unrestricted urban reuse, for those states that do not specify limitations on BOD or TSS, a particular level of treatment is usually specified.

Average fecal coliform limits range from non-detectable to 200/100 ml, with some states allowing higher single sample fecal coliform limits. As for unrestricted urban reuse, Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 ml. Arizona and Texas require that no single fecal coliform count exceed 800/100 ml.

Washington is the only state that sets a limit on turbidity for restricted urban reuse with an average turbidity limit of 2 NTU and a not-to-exceed at any time limit of 5 NTU.

At this time, no states have set limits on certain pathogenic organisms for restricted urban reuse. However, Florida does require monitoring of *Giardia* and *Cryptosporidium* with sampling frequency as noted in Section 4.1.1.1.

4.1.1.3 Agricultural Reuse - Food Crops

The use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow irrigation of food crops with reclaimed water only if the crop is to be processed and not eaten raw. Nevada allows only surface irrigation of fruit or nut bearing trees. Treatment requirements range from secondary treatment in Nevada for irrigation of processed food crops, to oxidation, coagulation, filtration, and disinfection in Arizona, California, Florida, Hawaii, and Washington. **Table 4-5** shows the reclaimed water quality and treatment requirements for irrigation of food crops.

Most states require a high level of treatment when reclaimed water is used for edible crops, especially those that are to be consumed raw. As in other reuse applications, however, existing regulations on treatment and water quality requirements vary from state to state and depend largely on the type of irrigation employed and the type of food crop being irrigated. For example, for foods consumed raw, Washington requires that the reclaimed water be oxidized and disinfected when surface irrigation is used, with the mean total coliform count not to exceed 2.2/100 ml. When spray irrigation is utilized, Washington requires that the reclaimed water be oxidized, coagulated, filtered, and disinfected, with the mean total coliform count not to exceed 2.2/100 ml. For processed foods, Washington requires only oxidation and disinfection regardless of the type of irrigation, with a 7-day mean total coliform count of 240/100 ml.

Where specified, limits on BOD range from 5 mg/l to 30 mg/l. Texas requires a monthly average BOD limit of 5 mg/l when reclaimed water will be used to irrigate unprocessed food crops. In Texas, spray irrigation is not permitted on foods that may be consumed raw, and only irrigation types that avoid reclaimed water contact with edible portions of food crops are acceptable. Florida requires that the annual average CBOD not exceed 20 mg/l after secondary treatment with filtration and high-level disinfection, while Texas requires that the BOD not exceed 30 mg/l (monthly average) when the reclaimed water is treated using a pond system and is to be used to irrigate food crops undergoing processing.

Limits on TSS vary from 5 mg/l to 30 mg/l. Florida requires that TSS not exceed 5.0 mg/l in any one sample prior to disinfection, while Washington requires that the TSS not exceed 30 mg/l (monthly average). In Florida, direct contact (spray) irrigation of edible crops that will not be peeled, skinned, cooked, or thermally-processed before consumption is not allowed except for tobacco and citrus. Indirect contact methods (ridge and furrow, drip, subsurface application system) can be used on any type of edible crop. California allows for direct contact irrigation with the edible portion of the crop.

Average fecal and total coliform limits range from non-detectable to 200/100 ml. Arizona requires no detectable limit for fecal coliform when reclaimed water will be used for spray irrigation of food crops. Florida requires that 75 percent of the fecal coliform samples taken over a 30-day period be below detectable levels, with no single sample in excess of 25/100 ml. Conversely, Nevada requires a maximum fecal coliform count of less than 400/100 ml with only surface irrigation of fruit and nut bearing trees. Again, some states allow higher single sample coliform counts.

Limits on turbidity range from 2 to 10 NTU. For example, California requires that turbidity not exceed 2 NTU within a 24-hour period, not exceed 5 NTU more than 5 percent of the time, and not exceed a maximum of 10 NTU at any time for reclaimed water that has been coagulated and passed through natural undisturbed soils or a bed of filter media and is irrigated on food crops to be consumed raw. California requires that the turbidity not exceed 0.2 NTU more than 5 percent of the time and not exceed a maximum of 0.5 NTU at any time for reclaimed water that has been passed through a membrane and is irrigated on food crops to be consumed raw. Hawaii requires that the detectable turbidity not exceed 5 NTU for more than 15 minutes and never exceed 10 NTU prior to filtration for reclaimed water used for spray irrigation of food crops.

At this time, no states have set limits on certain pathogenic organisms for agricultural reuse on food crops. Florida does require monitoring of *Giardia* and *Cryptosporidium* with sampling frequency as noted in Section 4.1.1.1.

4.1.1.4 Agricultural Reuse – Non-food Crops

The use of reclaimed water for agricultural irrigation of non-food crops presents a reduced opportunity of human exposure to the water, resulting in less stringent treatment and water quality requirements than other forms of reuse. In the majority of the states, secondary treatment followed by disinfection is required, although Hawaii also requires filtration. **Table 4-6** shows the reclaimed water quality and treatment requirements for irrigation of non-food crops.

Where specified, limits on BOD range from 5 mg/l to 30 mg/l. Texas requires that BOD not exceed 5 mg/l (monthly average) except when reclaimed water is used for landscape impoundments, in which case BOD is limited to 10 mg/l. Florida requires that the annual average CBOD not exceed 20 mg/l after secondary treatment and basic disinfection. Washington and Nevada require that BOD not exceed 30 mg/l as a monthly average. Limits on TSS vary from 20 mg/l to 30 mg/l. Florida requires that the annual average TSS not exceed 20 mg/l except when a subsurface application is used, in which case the single sample TSS limit is 10 mg/l. Washington requires a monthly mean of 30 mg/l TSS.

Average fecal and total coliform limits range from 2.2/100 ml for Hawaii to 200/100 ml for Arizona and Florida. There are several states that do not require disinfection if certain buffer requirements are met. For example, Nevada requires no disinfection with a minimum buffer zone of 800 feet for spray irrigation of non-food crops. Some states allow higher single sample coliform counts. For example, Arizona requires that no single fecal coliform count ex-

Table 4-6. Agricultural Reuse - Non-Food Crops

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment and disinfection	Secondary-23, Oxidized, and disinfected	Secondary treatment, basic disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	20 mg/l	NS	NS	NS	30 mg/l
Turbidity	NS	NS	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
							5 NTU (Max)
Coliform	**Fecal**	**Total**	**Fecal**	**Fecal**	**Fecal**	**Fecal**	**Total**
	200/100 ml (Avg)	23/100 ml (Avg)	200/100 ml (Avg)	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	23/100 ml (Avg)
	800/100 ml (Max)	240/100 ml (Max in 30 days)	800/100 ml (Max)	23/100 ml (Max)	400/100 ml (Max)	75/100 ml (Max)	240/100 ml (Max)

(1) NS - Not specified by state regulations

ceed 4,000/100 ml when reclaimed water will be used for irrigation of pasture for non-dairy animals.

At this time, Hawaii, Texas, and Washington require limits on turbidity for reclaimed water used for agricultural reuse on non-food crops. Washington requires that the turbidity not exceed 2 NTU as an average and not exceed 5 NTU at any time. Texas requires a turbidity limit of 3 NTU for reclaimed water that will be used for irrigation of pastures for milking animals. Hawaii, on the other hand, requires the detectable turbidity not exceed 5 NTU for more than 15 minutes and never exceed 10 NTU prior to filtration for reclaimed water used for spray irrigation of pastures for milking and other animals.

At this time, no states have set limits on certain pathogenic organisms for agricultural reuse on non-food crops.

4.1.1.5 Unrestricted Recreational Reuse

As with unrestricted urban reuse, unrestricted recreational reuse involves the use of reclaimed water where public exposure is likely, thereby necessitating a high degree of treatment. Only 4 of the 7 states (California, Nevada, Texas, and Washington) have regulations or guidelines pertaining to unrestricted recreational reuse. **Table 4-7** shows the reclaimed water quality and treatment requirements for unrestricted recreational reuse. Nevada requires secondary treatment with disinfection, while California requires oxidation, coagulation, clarification, filtration, and disinfection. Where specified, limits on BOD range from 5 mg/l to 30 mg/l. Texas requires that BOD not exceed 5 mg/l as a monthly average, while Washington requires that BOD not exceed 30 mg/l prior to unrestricted recreational reuse. Washington is the only state to set a limit on TSS and requires 30 mg/l or less as a monthly average. All states, except Texas, require that the median total coliform count not exceed 2.2/100 ml, with no single sample to exceed 23/100 ml. Texas requires that the median fecal coliform count not exceed 20/100 ml, with no single sample to exceed 75/100 ml.

Limits on turbidity generally range from 2 NTU to 5 NTU. Most of the states require an average turbidity limit of 2 NTU and a not-to-exceed limit of 5 NTU. California specifies different turbidity requirements for wastewater that has been coagulated and passed through natural and undisturbed soils or a bed of filter media as well as wastewater passed through membranes. For the first, turbidity is not to exceed 5 NTU for more than 5 percent of the time within a 24-hour period and not to exceed 10 NTU at any time. For the latter, turbidity is not to exceed 0.2 NTU more than 5 percent of the time within a 24-hour period and not to exceed 0.5 NTU at any time. Texas requires a turbidity limit of 3 NTU, and Nevada does not specify a limit on turbidity.

Table 4-7. Unrestricted Recreational Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (1)	Oxidized, coagulated, clarified, filtered, and disinfected	NR	NR	Secondary treatment and disinfection	NS	Oxidized, coagulated, filtered, and disinfected
BOD_5	NR	NS(2)	NR	NR	30 mg/l	5 mg/l	30 mg/l
TSS	NR	NS	NR	NR	NS	NS	30 mg/l
Turbidity	NR	2 NTU (Avg)	NR	NR	NS	3 NTU	2 NTU (Avg)
		5 NTU (Max)					5 NTU (Max)
Coliform	NR	**Total**	NR	NR	**Fecal**	**Fecal**	**Fecal**
		2.2/100 ml (Avg)			2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
		23/100 ml (Max in 30 days)			23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

Table 4-8. Restricted Recreational Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Secondary-23, oxidized, and disinfected	NR (1)	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS	Oxidized and disinfected
BOD_5	NS(2)	NS	NR	NS	30 mg/l	20 mg/l	30 mg/l
TSS	NS	NS	NR	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	NS	NR	2 NTU (Max)	NS	NS	2 NTU (Avg)
	5 NTU (Max)						5 NTU (Max)
Coliform	**Fecal**	**Total**	NR	**Fecal**	**Fecal**	**Fecal**	**Total**
	None detectable (Avg)	2.2/100 ml (Avg)		2.2/100 ml (Avg)	200/100 ml (Avg)	200/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)		23/100 ml (Max)	23/100 ml (Max)	800/100 ml (Max)	23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

At this time, no states have set limits on certain pathogenic organisms for unrestricted recreational reuse.

4.1.1.6 Restricted Recreational Reuse

State regulations and guidelines regarding treatment and water quality requirements for restricted recreational reuse are generally less stringent than for unrestricted recreational reuse since the public exposure to the reclaimed water is less likely. Six of the 7 states (Arizona, California, Hawaii, Nevada, Texas, and Washington) have regulations pertaining to restricted recreational reuse. With the exception of Arizona and Hawaii, which require filtration, the remaining states require secondary treatment with disinfection. Texas does not specify treatment process requirements. **Table 4-8** shows the reclaimed water quality and treatment requirements for restricted recreational reuse.

Nevada, Texas, and Washington have set limits on BOD ranging from 20 mg/l to 30 mg/l as a monthly average. Only Washington has set limits on TSS of 30 mg/l as a monthly average. Arizona requires no detectable fecal coliform in 4 of the last 7 daily samples and a single sample maximum of 23/100 ml. California, Hawaii, Nevada, and Washington require that the median total coliform count not exceed 2.2/100 ml. Texas, on the other hand, requires that the median fecal coliform count not exceed 200/100 ml and that a single sample not exceed 800/100 ml.

Limits on turbidity are specified for Arizona, Hawaii, and Washington. Arizona and Washington require a turbidity of less than 2 NTU as an average and a not-to-exceed maximum of 5 NTU. Hawaii specifies an effluent turbidity requirement of 2 NTU. California, Nevada, and Texas have not specified turbidity requirements for restricted recreational reuse.

At this time, no states have set limits on certain pathogenic organisms for restricted recreational reuse.

4.1.1.7 Environmental - Wetlands

A review of existing reuse regulations shows only 2 of the 7 states (Florida and Washington) have regulations pertaining to the use of reclaimed water for creation of artificial wetlands and/or the enhancement of natural wetlands. **Table 4-9** shows the reclaimed water quality and treatment requirements for environmental reuse.

Florida has comprehensive and complex rules governing the discharge of reclaimed water to wetlands. Treatment and disinfection levels are established for different types of wetlands, different types of uses, and the degree of public access. Most wetland systems in Florida are used for tertiary wastewater treatment; and wetland creation, restoration, and enhancement projects can be considered reuse. Washington also specifies different treatment requirements for different types of wetlands and based on the degree of public access. General compliance requirements of 20 mg/l BOD and TSS, 3 mg/l total Kjeldahl nitrogen (TKN), and 1 mg/l total phosphorus must be met for all categories.

4.1.1.8 Industrial Reuse

Five of the 7 states (California, Florida, Hawaii, Texas, and Washington) have regulations or guidelines pertaining to industrial reuse of reclaimed water. **Table 4-10** shows the reclaimed water quality and treatment requirements for industrial reuse.

Reclaimed water quality and treatment requirements vary based on the final use of the reclaimed water and exposure potential (see Appendix A, Table A-8 for a sum-

Table 4-9. Environmental Reuse - Wetlands

	Arizona	California	Florida(1)	Hawaii	Nevada	Texas	Washington
Treatment	NR (2)	NR	Advanced treatment	NR	NR	NR	Oxidized, coagulated, and disinfected
BOD_5	NR	NR	5 mg/l $CBOD_5$	NR	NR	NR	20 mg/l
TSS	NR	NR	5 mg/l	NR	NR	NR	20 mg/l
Coliform	NR	NR	NS (3)	NR	NR	NR	**Fecal**
							2.2/100 ml (Avg)
							23/100 ml (Max)
Total Ammonia	NR	NR	2 mg/l	NR	NR	NR	Not to exceed chronic standards for freshwater
Total Phosphorus	NR	NR	1 mg/l	NR	NR	NR	1 mg/l

(1) Florida requirements are for discharge of reclaimed water to receiving wetlands
(2) NR - Not regulated by the state
(3) NS - Not specified by state regulations

Table 4-10. Industrial Reuse(1)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (2)	Oxidized and disinfected	Secondary treatment and basic disinfection	Oxidized and disinfected	NR	NS	Oxidized and disinfected
BOD_5	NR	NS (3)	20 mg/l	NS	NR	20 mg/l	NS
TSS	NR	NS	20 mg/l	NS	NR	---	NS
Turbidity	NR	NS	NS	NS	NR	3 NTU	NS
Coliform	NR	**Total**	**Fecal**	**Fecal**	NR	**Fecal**	**Total**
		23/100 ml (Avg)	200/100 ml (Avg)	23/100 ml (Avg)		200/100 ml (Avg)	23/100 ml (Avg)
		240/100 ml (Max in 30 days)	800/100 ml (Max)	200/100 ml (Max)		800/100 ml (Avg)	240/100 ml (Avg)

(1) All state requirements are minimum values. Additional treatment may be required depending on expected public exposure. Additional regulations for industrial systems are contained in Appendix A.
(2) NR - Not regulated by the state
(3) NS - Not specified by state regulations

mary of each state's regulations). For example, California has different requirements for the use of reclaimed water as cooling water, based on whether or not a mist is created. If a mist is created, oxidation, coagulation, filtration, and disinfection are required and total coliform limits of 2.2/100 ml as a weekly median must be met. If a mist is not created, only oxidation and disinfection are required and total coliform limits of 23/100 ml as a weekly median must be met.

4.1.1.9 Groundwater Recharge

Spreading basins, percolation ponds, and infiltration basins have a long history of providing both effluent disposal and groundwater recharge. Most state regulations allow for the use of relatively low quality water (i.e., secondary treatment with basic disinfection) based on the fact that these systems have a proven ability to provide additional treatment. Traditionally, potable water supplies have been protected by requiring a minimum separation between the point of application and any potable supply wells. These groundwater systems are also typically located so that their impacts to potable water withdrawal points are minimized. While such groundwater recharge systems may ultimately augment potable aquifers, that is not their primary intent and experience suggests current practices are protective of raw water supplies.

Based on a review of the existing reuse regulations and guidelines, California, Florida, Hawaii, and Washington have regulations or guidelines for reuse with the specific intent of groundwater recharge of aquifers. **Table 4-11** shows reclaimed water quality and treatment requirements for groundwater recharge via rapid-rate application systems.

For groundwater recharge, California and Hawaii do not specify required treatment processes and determine requirements on a case-by-case basis. The California and Hawaii Departments of Health Services base the evaluation on all relevant aspects of each project including treatment provided, effluent quality and quantity, effluent or application spreading area operation, soil characteristics, hydrogeology, residence time, and distance to withdrawal. Hawaii does require a groundwater monitoring program.

Washington has extensive guidelines for the use of reclaimed water for direct groundwater recharge of nonpotable aquifers. It requires Class A reclaimed wa-

Table 4-11. Groundwater Recharge (1)

	Arizona	California(2)	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (3)	Case-by-case basis	Secondary treatment and basic disinfection	Case-by-case basis	NR	NR	Oxidized, coagulated, filtered, and disinfected
BOD_5	NR		NS(4)		NR	NR	5 mg/l
TSS	NR		10.0 mg/l		NR	NR	5 mg/l
Turbidity	NR		NS		NR	NR	2 NTU (Avg) 5 NTU (Max)
Coliform	NR		NS		NR	NR	**Total** 2.2/100 ml (Avg) 23/100 ml (Max)
Total Nitrogen	NR		12 mg/l		NR	NR	NS

(1) All state requirements are for groundwater recharge via rapid-rate application systems. Additional regulations for recharge of potable aquifers are contained in Section 4.1.1.10 and Appendix A.
(2) Groundwater recharge in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

ter defined as oxidized, coagulated, filtered, and disinfected. Total coliform is not to exceed 2.2/100 ml as a 7-day median and 23/100 ml in any sample. Weekly average BOD and TSS limits are set at 5 mg/l. Turbidity is not to exceed 2 NTU as a monthly average and 5 NTU in any sample. Additionally, groundwater monitoring is required and is based on reclaimed water quality and quantity, site-specific soil and hydrogeologic characteristics, and other considerations. Washington also specifies that reclaimed water withdrawn for nonpotable purposes can be withdrawn at any distance from the point of injection and at any time after direct recharge.

Florida requires that TSS not exceed 5.0 mg/l in any sample, be achieved prior to disinfection, and that the total nitrogen in the reclaimed water be less than 12 mg/l. Florida also requires continuous on-line monitoring of turbidity; however, no limit is specified.

4.1.1.10 Indirect Potable Reuse

Indirect potable reuse involves the use of reclaimed water to augment surface water sources that are used or will be used for public water supplies or to recharge groundwater used as a source of domestic water supply. Unplanned indirect potable water reuse is occurring in many river systems today. Many domestic wastewater treatment plants discharge treated effluent to surface waters upstream of intakes for domestic water supply treatment plants. Additionally, many types of beneficial reuse projects inadvertently contribute to groundwater augmentation as an unintended result of the primary activity. For example, irrigation can replenish groundwater sources that will eventually be withdrawn for use as a potable water supply. Indirect potable reuse systems, as defined here, are distinguished from typical groundwater recharge systems and surface water discharges by both intent and proximity to subsequent withdrawal points for potable water use. Indirect potable reuse involves the intentional introduction of reclaimed water into the raw water supply for the purposes of increasing the total volume of water available for potable use. In order to accomplish this objective, the point at which reclaimed water is introduced into the environment must be selected to ensure it will flow to the point of withdrawal. Typically the design of these systems assumes there will be little to no additional treatment in the environment after discharge, and all applicable water quality requirements are met prior to release of the reclaimed water.

Based on a review of the existing reuse regulations and guidelines, 4 of the 7 states (California, Florida, Hawaii, and Washington) have regulations or guidelines pertaining to indirect potable reuse. For groundwater recharge of potable aquifers, most of the states require a pretreatment program, public hearing requirements prior to project approval, and a groundwater monitoring program. Florida and Washington require pilot plant studies to be performed. In general, all the states that specify treatment processes require secondary treatment with filtration and disinfection. Washington is the only state that specifies the wastewater must be treated by reverse osmosis. California and Hawaii do not specify the type of treatment processes required and determine requirements on a case-by-case basis.

Most states specify reclaimed water quality limitations for TSS, nitrogen, total organic carbon (TOC), turbidity, and total coliform. Florida requires that TSS not exceed 5.0 mg/l in any sample and be achieved prior to disinfection. Florida and Washington require the total nitrogen in the reclaimed water to be less than 10 mg/l. Washington has a limit of 1 mg/l for TOC, while Florida's limit is set at 3 mg/l as a monthly average. Florida also requires an average limit of 0.2 mg/l for total organic halides (TOX). Turbidity limits vary greatly where specified. For example, Washington specifies a limit of 0.1 NTU as a monthly average and 0.5 NTU as a maximum at any time. Florida requires continuous on-line monitoring of turbidity; however, no limit is specified. Fecal coliform limits also vary greatly from state to state. Washington requires a limit of 1/100 ml for total coliform as a weekly median and a not to exceed limit of 5/100 ml in any one sample for direct injection into a potable aquifer. The states that specify reclaimed water quality limitations require the reclaimed water to meet drinking water standards.

Most states specify a minimum time the reclaimed water must be retained underground prior to being withdrawn as a source of drinking water. Washington requires that reclaimed water be retained underground for a minimum of 12 months prior to being withdrawn as a drinking water supply. Several states also specify minimum separation distances between a point of recharge and the point of withdrawal as a source of drinking water. Florida requires a 500-foot (150-meter) separation distance between the zone of discharge and potable water supply well. Washington requires the minimum horizontal separation distance between the point of direct recharge and point of withdrawal as a source of drinking water supply to be 2,000 feet (610 meters). **Table 4-12** shows the reclaimed water quality and treatment requirements for indirect potable reuse.

Florida includes discharges to Class I surface waters (public water supplies) as indirect potable reuse. Discharges less than 24 hours travel time upstream from Class I waters are also considered as indirect potable reuse. Surface water discharges located more than 24 hours travel time to Class I waters are not considered indirect potable reuse. For discharge to Class I surface waters or water contiguous to or tributary to Class I waters (defined as a discharge located less than or equal to 4 hours travel time from the point of discharge to arrival at the boundary of the Class I water), secondary treatment with filtration, high-level disinfection, and any additional treatment required to meet TOC and TOX limits is required. The reclaimed water must meet primary and secondary drinking water standards, except for asbestos, prior to discharge. TSS must not exceed 5.0 mg/l in any sample prior to disinfection and total nitrogen cannot exceed 10 mg/l as an annual average. The reclaimed water must also meet TOC limitations of 3 mg/l as a monthly average and 5 mg/l in any single sample. Outfalls for surface water discharges are not to be located within 500 feet (150 meters) of existing or approved potable water intakes within Class I surface waters.

4.1.2 Reclaimed Water Monitoring Requirements

Reclaimed water monitoring requirements vary greatly from state to state and again depend on the type of reuse. For unrestricted urban reuse, Oregon requires sampling for coliform daily, while for agricultural reuse of non-food crops, sampling for total coliform is only required once a week. Oregon also requires hourly monitoring of turbidity when a limit on turbidity is specified.

For unrestricted and restricted urban reuse, as well as agricultural reuse on food crops, Florida requires the continuous on-line monitoring of turbidity and chlorine residual. Even though no limits on turbidity are specified in Florida, continuous monitoring serves as an on-line surrogate for suspended solids. In addition, Florida requires that the TSS limit be achieved prior to disinfection and has a minimum schedule for sampling and testing flow, pH, chlorine residual, dissolved oxygen, TSS, CBOD, nutrients, and fecal coliform based on system capacity. Florida also requires an annual analysis of primary and secondary drinking water standards for reclaimed water used in irrigation for facilities greater than 100,000 gpd (4.4 l/s). Monitoring for *Giardia* and *Cryptosporidium* must also be performed with frequency dependent on system capacity. Other states determine monitoring requirements on a case-by-case basis depending on the type of reuse.

4.1.3 Treatment Facility Reliability

Some states have adopted facility reliability regulations or guidelines in place of, or in addition to, water quality

Table 4-12. Indirect Potable Reuse (1)

	Arizona	California(2)	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (3)	Case-by-case basis	Advanced treatment, filtration, and high-level disinfection	Case-by-case basis	NR	NR	Oxidized, coagulated, filtered, reverse-osmosis treated, and disinfected
BOD_5	NR		20 mg/l		NR	NR	5 mg/l
TSS	NR		5.0 mg/l		NR	NR	5 mg/l
Turbidity	NR		NS (4)		NR	NR	0.1 NTU (Avg) 0.5 NTU (Max)
Coliform	NR		**Total** All samples less than detection		NR	NR	**Total** 1/100 ml (Avg) 5/100 ml (Max)
Total Nitrogen	NR		10 mg/l		NR	NR	10 mg/l
TOC	NR		3 mg/l (Avg) 5 mg/l (Max)		NR	NR	1.0 mg/l
Primary and Secondary Standards	NR		Compliance with most primary and secondary		NR	NR	Compliance with most primary and secondary

(1) Florida requirements are for the planned use of reclaimed water to augment surface water sources that will be used as a source of domestic water supply
(2) Indirect potable reuse in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

requirements. Generally, requirements consist of alarms warning of power failure or failure of essential unit processes, automatic standby power sources, emergency storage, and the provision that each treatment process be equipped with multiple units or a back-up unit.

Articles 8, 9, and 10 of California's Title 22 regulations provide design and operational considerations covering alarms, power supply, emergency storage and disposal, treatment processes, and chemical supply, storage, and feed facilities. For treatment processes, a variety of reliability features are acceptable in California. For example, for all biological treatment processes, one of the following is required:

- Alarm (failure and power loss) and multiple units capable of producing biologically oxidized wastewater with one unit not in operation
- Alarm (failure and power loss) and short-term (24-hour) storage or disposal provisions and standby replacement equipment
- Alarm (failure and power loss) and long-term (20-day) storage or disposal provisions

Florida requires Class I reliability of treatment facilities when reclaimed water is used for irrigation of food crops and for restricted and unrestricted urban reuse. Class I reliability requires multiple treatment units or back-up units and a secondary power source. In addition, a minimum of 1 day of reject water storage is required to store reclaimed water of unacceptable quality for additional treatment. Florida also requires staffing at the water reclamation facility 24 hours/day, 7 days/week or 6 hours/day, 7 days/week. The minimum staffing requirement may be reduced to 6 hours/day, 7 days/week if reclaimed water is delivered to the reuse system only during periods when a qualified operator is present, or if additional reliability features are provided.

Florida has also established minimum system sizes for treatment facilities to aid in assuring the continuous production of high-quality reclaimed water. Minimum system size for unrestricted and restricted urban reuse and for use on edible crops is 0.1 mgd (4.4 l/s). A minimum system size is not required if reclaimed water will be used only for toilet flushing and fire protection uses.

Other states that have regulations or guidelines regarding treatment facility reliability include Georgia, Hawaii, Indiana, Massachusetts, North Carolina, Oregon, Utah, Washington, and Wyoming. Washington's guidelines pertaining to treatment facility reliability are similar to California's regulations. Georgia, Massachusetts, North Carolina, Oregon, and Wyoming require that multiple treatment units be provided for all essential treatment processes and a secondary or back-up power source be supplied.

4.1.4 Reclaimed Water Storage

Current regulations and guidelines regarding storage requirements are primarily based upon the need to limit or prevent surface water discharge and are not related to storage required to meet diurnal or seasonal variations in supply and demand. Storage requirements vary from state to state and are generally dependent upon geographic location and site conditions. For example, Florida requires a minimum storage volume equal to 3 days of the average design flow, while South Dakota requires a minimum storage volume of 210 days of the average design flow. The large difference in time is primarily due to the high number of non-irrigation days due to freezing temperatures in the northern states. In addition to the minimum storage requirement, Florida also requires that a water balance be performed based on a 1-in-10 year rainfall recurrence interval and a minimum of 20 years of climatic data to determine if additional storage is required beyond the minimum requirement of 3 days.

Most states that specify storage requirements do not differentiate between operational and seasonal storage, with the exception of Delaware, Georgia, and Ohio, which require that both operational and wet weather storage be considered. The majority of states that have storage requirements in their regulations or guidelines require that a water balance be performed on the reuse system, taking into account all inputs and outputs of water to the system based on a specified rainfall recurrence interval.

Presently, Florida is the only state with regulations or guidelines for aquifer storage and recovery (ASR) of reclaimed water. ASR systems using reclaimed water are required to meet the technical and permitting requirements of Florida's Department of Environmental Protection underground injection control program and obtain an underground injection control construction and operation permit in addition to the domestic wastewater permit. Water recovered from the ASR system must meet the performance standards for fecal coliform as specified for high-level disinfection. Specifically, the fecal coliform limits require 75 percent of samples to be below detection limits, and any single sample is not to exceed 25/100 ml before use in a reuse system. Preapplication treatment and disinfection requirements vary depending on the class of groundwater receiving injected reclaimed water, but may be as stringent as to require that reclaimed water meet primary and secondary drinking water standards and TOC and TOX limits prior to injection. Monitoring of the reclaimed water prior to injection and after recovery from the ASR system is required. In addition, a groundwater monitoring plan must be implemented before placing the ASR system into operation. The monitoring plan must be designed to verify compliance with the groundwater standards and to monitor the performance of the ASR system. As part of the monitoring plan, a measure of inorganics concentration (such as chlorides or total dissolved solids) and specific conductance of the water being injected, the groundwater, and the recovered water are required to be monitored. In some cases, an extended zone of discharge for the secondary drinking water standards and for sodium can be approved.

Injection wells and recovery wells used for ASR are to be located at least 500 feet from any potable water supply well. For potable water supply wells that are not public water supply wells, a smaller setback distance may be approved if it can be demonstrated that confinement exists such that the system will not adversely affect the quantity or quality of the water withdrawn from the potable water supply well. If the ASR well is located in the same aquifer as a public supply well, the permitting agencies may require a detailed analysis of the potential for reclaimed water entry into the public supply well.

4.1.5 Application Rates

When regulations specify application or hydraulic loading rates, the regulations generally pertain to land application systems that are used primarily for additional wastewater treatment for disposal rather than reuse. When systems are developed chiefly for the purpose of land treatment and/or disposal, the objective is often to dispose of as much effluent on as little land as possible;

thus, application rates are often far greater than irrigation demands and limits are set for the maximum hydraulic loading. On the other hand, when the reclaimed water is managed as a valuable resource, the objective is to apply the water according to irrigation needs rather than maximum hydraulic loading, and application limits are rarely specified.

Many states do not have any specific requirements regarding reclaimed water irrigation application rates, as these are generally based on site conditions; however, most states emphasizing beneficial reuse recommend a maximum hydraulic loading rate of no more than 2 inches per week (5.1 cm per week). Delaware's regulations require that the maximum design wastewater loading be limited to 2.5 inches per week (6.4 cm per week). Florida recommends a maximum annual average of 2 inches per week (5.1 cm per week). Those states emphasizing land treatment or disposal may recommend a hydraulic loading rate of up to 4 inches per week (10.2 cm per week).

In addition to hydraulic loading rates, some states also have limits on nitrogen loading. For example, Alabama, Arkansas, and Tennessee all require that the effluent from the reuse system have a nitrate-nitrogen concentration of 10 mg/l or less, while Missouri and Nebraska both require that the nitrogen loading not exceed the nitrogen uptake of the crop.

4.1.6 Groundwater Monitoring

Groundwater monitoring programs associated with reclaimed water irrigation generally focus on water quality in the surficial aquifer and are required by Alabama, Arkansas, Delaware, Florida, Hawaii, Illinois, Iowa, Massachusetts, Missouri, New York, Ohio, Pennsylvania, South Carolina, South Dakota, Tennessee, West Virginia, and Wisconsin. In general, these groundwater monitoring programs require that 1 well be placed hydraulically upgradient of the reuse site to assess background and incoming groundwater conditions within the aquifer in question. In addition 2 wells must be placed hydraulically downgradient of the reuse site to monitor compliance. Florida normally requires a minimum of 3 monitoring wells at each reuse site. For reuse projects involving multiple sites, Florida may allow monitoring at selected example sites. Some states also require that a well be placed within each reuse site. South Carolina's guidelines suggest that a minimum of 9 wells be placed in golf courses (18 holes) that irrigate with reclaimed water. Sampling parameters and frequency of sampling are generally considered on a case-by-case basis.

4.1.7 Setback Distances for Irrigation

Many states have established setback distances or buffer zones between reuse irrigation sites and various facilities such as potable water supply wells, property lines, residential areas, and roadways. Setback distances vary depending on the quality of reclaimed water and the method of application. For example, Nevada requires a 400- to 800-foot (120- to 240-meter) buffer, depending on disinfection level, for a spray irrigation system, but when surface irrigation is used as the application method, no buffer is required. For restricted and unrestricted urban reuse and irrigation of food crops, Florida requires a 75-foot (23-meter) setback to potable water supply wells; but for agricultural reuse on non-food crops, Florida requires a 500-foot (150-meter) setback to potable water supply wells and a 100-foot (30-meter) setback to property lines. Florida will allow reduced setback distances for agricultural reuse on non-food crops if additional disinfection and reliability are provided or if alternative application techniques are used. Colorado recommends a 500-foot (150-meter) setback distance to domestic supply wells and a 100-foot (30-meter) setback to any irrigation well regardless of the quality of the reclaimed water.

Due to the high degree of treatment required, Oregon and Nevada do not require setback distances when reclaimed water is used for unrestricted urban reuse or irrigation of food crops. However, setback distances are required for irrigation of non-food crops and restricted urban reuse. In Nevada, the quality requirements for reclaimed water are based not only on the type of reuse, but also on the setback distance. For example, for restricted urban reuse and a 100-foot (30-meter) buffer zone, Nevada requires that the reclaimed water have a mean fecal coliform count of no more than 23/100 ml and not exceed a maximum daily number of 240/100 ml. However, with no buffer zone, the reclaimed water must have a mean fecal coliform count of no more than 2.2/100 ml and not exceed a maximum daily number of 23/100 ml.

4.2 Suggested Guidelines for Water Reuse

Table 4-13 presents suggested wastewater treatment processes, reclaimed water quality, monitoring, and setback distances for various types of water reuse. Suggested guidelines are presented for the following categories:

- Urban Reuse
- Restricted Access Area Irrigation

- Agricultural Reuse - Food Crops
    - Food crops not commercially processed
    - Commercially processed food crops and surface irrigation of orchards and vineyards

- Agricultural Reuse – Non-Food Crops
    - Pasture for milking animals and fodder, fiber, and seed crops

- Recreational Impoundments

- Landscape Impoundments

- Construction Uses

- Industrial Reuse

- Environmental Reuse

- Groundwater Recharge
    - Spreading or injection into aquifers not used for public water supply

- Indirect Potable Reuse
    - Spreading into potable aquifers
    - Injection into potable aquifers
    - Augmentation of surface supplies

These guidelines apply to domestic wastewater from municipal or other wastewater treatment facilities having a limited input of industrial waste. The suggested guidelines are predicated principally on water reclamation and reuse information from the U.S. and are intended to apply to reclamation and reuse facilities in the U.S. Local social, economic, regulatory, technological, and other conditions may limit the applicability of these guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by the United States Agency for International Development (USAID) as strict criteria for funding.

The suggested treatment processes, reclaimed water quality, monitoring frequency, and setback distances are based on:

- Water reuse experience in the U.S. and elsewhere

- Research and pilot plant or demonstration study data

- Technical material from the literature

- Various states' reuse regulations, policies, or guidelines (see Appendix A)

- Attainability

- Sound engineering practice

These guidelines are not intended to be used as definitive water reclamation and reuse criteria. They are intended to provide reasonable guidance for water reuse opportunities, particularly in states that have not developed their own criteria or guidelines.

Adverse health consequences associated with the reuse of raw or improperly treated wastewater are well documented. As a consequence, water reuse regulations and guidelines are principally directed at public health protection and generally are based on the control of pathogenic microorganisms for nonpotable reuse applications and control of both health significant microorganisms and chemical contaminants for indirect potable reuse applications. These guidelines address health protection via suggested wastewater treatment unit processes, reclaimed water quality limits, and other controls (setback distances, etc.).

Both treatment processes and water quality limits are recommended for the following reasons:

- Water quality criteria that include the use of surrogate parameters may not adequately characterize reclaimed water quality.

- A combination of treatment and quality requirements known to produce reclaimed water of acceptable quality obviate the need to monitor the finished water for certain constituents, e.g., some health-significant chemical constituents or pathogenic microorganisms.

- Expensive, time-consuming, and, in some cases, questionable monitoring for pathogenic organisms, such as viruses, is eliminated without compromising health protection.

- Treatment reliability is enhanced.

It would be impractical to monitor reclaimed water for all of the chemical constituents and pathogenic organisms of concern, and surrogate parameters are universally accepted. In the U.S., total and fecal coliforms are the most commonly used indicator organisms in reclaimed water as a measure of disinfection efficiency. While coliforms are adequate indicator organisms for many bacterial pathogens, they are, by themselves, poor indicators of parasites and viruses. The total coliform analysis includes enumeration of organisms of both fecal and nonfecal origin, while the fecal coliform analysis is spe-

Table 4-13. Suggested Guidelines for Water Reuse [1]

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Urban Reuse All types of landscape irrigation, (e.g., golf courses, parks, cemeteries) – also vehicle washing, toilet flushing, use in fire protection systems and commercial air conditioners, and other uses with similar access or exposure to the water	◆ Secondary [4] ◆ Filtration [5] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 10 mg/l BOD [7] ◆ ≤ 2 NTU [8] ◆ No detectable fecal coli/100 ml [9,10] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ Turbidity - continuous ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 50 ft (15 m) to potable water supply wells	◆ See Table 2-7 for other recommended limits. ◆ At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve < 14 fecal coli/100 ml, may be appropriate. ◆ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ◆ The reclaimed water should not contain measurable levels of viable pathogens. [12] ◆ Reclaimed water should be clear and odorless. ◆ A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ◆ A chlorine residual of 0.5 mg/l or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. ◆ See Section 3.4.3. for recommended treatment reliability.
Restricted Access Area Irrigation Sod farms, silviculture sites, and other areas where public access is prohibited, restricted or infrequent	◆ Secondary [4] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 300 ft (90 m) to potable water supply wells ◆ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	◆ See Table 2-7 for other recommended limits. ◆ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ◆ See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Food Crops Not Commercially Processed [15] Surface or spray irrigation of any food crop, including crops eaten raw.	◆ Secondary [4] ◆ Filtration [5] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 10 mg/l BOD [7] ◆ ≤ 2 NTU [8] ◆ No detectable fecal coli/100 ml [9,10] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ Turbidity - continuous ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 50 ft (15 m) to potable water supply wells	◆ See Table 2-7 for other recommended limits. ◆ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ◆ The reclaimed water should not contain measurable levels of viable pathogens. [12] ◆ A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ◆ High nutrient levels may adversely affect some crops during certain growth stages. ◆ See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Food Crops Commercially Processed [15] Surface Irrigation of Orchards and Vineyards	◆ Secondary [4] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ < 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 300 ft (90 m) to potable water supply wells ◆ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	◆ See Table 2-7 for other recommended limits. ◆ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ◆ High nutrient levels may adversely affect some crops during certain growth stages. ◆ See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Non-food Crops Pasture for milking animals; fodder, fiber, and seed crops	◆ Secondary [4] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ < 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 300 ft (90 m) to potable water supply wells ◆ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	◆ See Table 2-7 for other recommended limits. ◆ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ◆ High nutrient levels may adversely affect some crops during certain growth stages. ◆ Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 ml, should be provided if this waiting period is not adhered to. ◆ See Section 3.4.3 for recommended treatment reliability.

Table 4-13. Suggested Guidelines for Water Reuse [1]

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Recreational Impoundments Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed	◆ Secondary [4] ◆ Filtration [5] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 10 mg/l BOD [7] ◆ ≤ 2 NTU [8] ◆ No detectable fecal coli/100 ml [9,10] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ Turbidity - continuous ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	◆ Dechlorination may be necessary to protect aquatic species of flora and fauna. ◆ Reclaimed water should be non-irritating to skin and eyes. ◆ Reclaimed water should be clear and odorless. ◆ Nutrient removal may be necessary to avoid algae growth in impoundments. ◆ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ◆ The reclaimed water should not contain measurable levels of viable pathogens. [12] ◆ A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ◆ Fish caught in impoundments can be consumed. ◆ See Section 3.4.3. for recommended treatment reliability.
Landscape Impoundments Aesthetic impoundment where public contact with reclaimed water is not allowed	◆ Secondary [4] ◆ Disinfection [6]	◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	◆ Nutrient removal may be necessary to avoid algae growth in impoundments. ◆ Dechlorination may be necessary to protect aquatic species of flora and fauna. ◆ See Section 3.4.3 for recommended treatment reliability.
Construction Use Soil compaction, dust control, washing aggregate, making concrete	◆ Secondary [4] ◆ Disinfection [6]	◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous		◆ Worker contact with reclaimed water should be minimized. ◆ A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 ml, should be provided when frequent work contact with reclaimed water is likely. ◆ See Section 3.4.3 for recommended treatment reliability.
Industrial Reuse Once-through cooling	◆ Secondary [4] ◆ Disinfection [6]	◆ pH = 6-9 ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	▪ pH - weekly ▪ BOD - weekly ▪ TSS - daily ▪ Coliform - daily ▪ Cl_2 residual - continuous	◆ 300 ft (90 m) to areas accessible to the public	◆ Windblown spray should not reach areas accessible to workers or the public.
Recirculating cooling towers	◆ Secondary [4] ◆ Disinfection [6] (chemical coagulation and filtration [5] may be needed)	◆ Variable depends on recirculation ratio (see Section 2.2.1) pH = 6-9 ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14] ◆ 1 mg/l Cl_2 residual (minimum) [11]	◆ pH - weekly ◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous	◆ 300 ft (90 m) to areas accessible to the public. May be reduced or eliminated if high level of disinfection is provided.	◆ Windblown spray should not reach areas accessible to workers or the public. ◆ Additional treatment by user is usually provided to prevent scaling, corrosion, biological growths, fouling and foaming. ◆ See Section 3.4.3 for recommended treatment reliability.
Other Industrial Uses	Depends on site specific uses (See Section 2.2.3)				
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation	◆ Variable ◆ Secondary [4] and disinfection [6] (minimum)	Variable, but not to exceed: ◆ ≤ 30 mg/l BOD [7] ◆ ≤ 30 mg/l TSS ◆ ≤ 200 fecal coli/100 ml [9,13,14]	◆ BOD - weekly ◆ TSS - daily ◆ Coliform - daily ◆ Cl_2 residual - continuous		◆ Dechlorination may be necessary to protect aquatic species of flora and fauna. ◆ Possible effects on groundwater should be evaluated. ◆ Receiving water quality requirements may necessitate additional treatment. ◆ The temperature of the reclaimed water should not adversely affect ecosystem. ◆ See Section 3.4.3 for recommended treatment reliability.

Table 4-13. Suggested Guidelines for Water Reuse [1]

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Groundwater Recharge By spreading or injection into aquifers not used for public water supply	- Site-specific and use dependent - Primary (minimum) for spreading - Secondary [4] (minimum) for injection	- Site-specific and use dependent	- Depends on treatment and use	- Site-specific	- Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers - See Section 2.5 for more information. - For spreading projects, secondary treatment may be needed to prevent clogging. - For injection projects, filtration and disinfection may be needed to prevent clogging. - See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers	- Secondary [4] - Disinfection [6] - May also need filtration [5] and/or advanced wastewater treatment [16]	- Secondary [4] - Disinfection [6] - Meet drinking water standards after percolation through vadose zone	Includes, but not limited to, the following: - pH - daily - Coliform - daily - Cl_2 residual - continuous - Drinking water standards - quarterly - Other [17] - depends on constituent - BOD - weekly - Turbidity - continuous	- 500 ft (150 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	- The depth to groundwater (i.e., thickness to the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. - The reclaimed water should be retained underground for at least 6 months prior to withdrawal. - Recommended treatment is site-specific and depends on factors such as type of soil, percolation rate, thickness of vadose zone, native groundwater quality, and dilution. - Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. - See Sections 2.5 and 2.6 for more information. - The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] - See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	- Secondary [4] - Filtration [5] - Disinfection [6] - Advanced wastewater treatment [16]	Includes, but not limited to, the following: - pH = 6.5 - 8.5 - $\le$ 2 NTU 8 - No detectable total coli/100 ml [9,10] - 1 mg/l Cl2 residual (minimum) [11] - $\le$ 3 mg/l TOC - $\le$ 0.2 mg/l TOX - Meet drinking water standards	Includes, but not limited to, the following: - pH - daily - Turbidity - continuous - Total coliform - daily - Cl_2 residual - continuous - Drinking water standards - quarterly - Other [17] - depends on constituent	- 2000 ft (600 m) to extraction wells. May vary depending on site-specific conditions.	- The reclaimed water should be retained underground for at least 9 months prior to withdrawal. - Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. - Recommended quality limits should be met a the point of injection. - The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] - See Sections 2.5 and 2.6 for more information. - A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. - See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Augmentation of surface supplies	- Secondary [4] - Filtration [5] - Disinfection [6] - Advanced wastewater treatment [16]	Includes, but not limited to, the following: - pH = 6.5 - 8.5 - $\le$ 2 NTU [8] - No detectable total coli/100 ml [9,10] - 1 mg/l Cl2 residual (minimum) [11] - $\le$ 3 mg/l TOC - Meet drinking water standards	Includes, but not limited to, the following: - pH - daily - Turbidity - continuous - Total coliform - daily - Cl_2 residual - continuous - Drinking water standards - quarterly - Other [17] - depends on constituent	- Site-specific	- Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. - The reclaimed water should not contain measurable levels of viable pathogens. [12] - See Sections 2.6 for more information. - A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. - See Section 3.4.3 for recommended treatment reliability.

Footnotes

1. These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in may areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by USAID as strict criteria for funding.

2. Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

3. Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

4. Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and may include stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/l.

5. Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite, filter cloth, or the passing of wastewater through microfilters or other membrane processes.

6. Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, UV radiation, ozonation, other chemical disinfectants, membrane processes, or other processes. The use of chlorine as defining the level of disinfection does not preclude the use of other disinfection processes as an acceptable means of providing disinfection for reclaimed water.

7. As determined from the 5-day BOD test.

8. The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If TSS is used in lieu of turbidity, the TSS should not exceed 5 mg/l.

9. Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation-tube technique may be used.

10. The number of fecal coliform organisms should not exceed 14/100 ml in any sample.

11. Total chlorine residual should be met after a minimum contact time of 30 minutes.

12. It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementa tion of a reuse program.

13. The number of fecal coliform organisms should not exceed 800/100 ml in any sample.

14. Some stabilization pond systems may be able to meet this coliform limit without disinfection.

15. Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

16. Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.

17. Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or uspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

cific for coliform organisms of fecal origin. Therefore, fecal coliforms are better indicators of fecal contamination than total coliforms, and these guidelines use fecal coliform as the indicator organism. Either the multiple-tube fermentation technique or the membrane filter technique may be used to quantify the coliform levels in the reclaimed water.

The *Guidelines* suggest that, regardless of the type of reclaimed water use, some level of disinfection should be provided to avoid adverse health consequences from inadvertent contact or accidental or intentional misuse of a water reuse system. For nonpotable uses of reclaimed water, 2 levels of disinfection are recommended. Reclaimed water used for applications where no direct public or worker contact with the water is expected should be disinfected to achieve an average fecal coliform concentration not exceeding 200/100 ml because:

- Most bacterial pathogens will be destroyed or reduced to low or insignificant levels in the water
- The concentration of viable viruses will be reduced somewhat
- Disinfection of secondary effluent to this coliform level is readily achievable at minimal cost
- Significant health-related benefits associated with disinfection to lower, but not pathogen-free, levels are not obvious

For uses where direct or indirect contact with reclaimed water is likely or expected, and for dual water systems where there is a potential for cross-connections with potable water lines, disinfection to produce reclaimed water having no detectable fecal coliform organisms per 100 ml is recommended. This more restrictive disinfection level is intended for use in conjunction with tertiary treatment and other water quality limits, such as a turbidity less than or equal to 2 NTU in the wastewater prior to disinfection. This combination of treatment and use of water quality limits has been shown to produce reclaimed water that is essentially free of measurable levels of bacterial and viral pathogens.

For indirect potable uses of reclaimed water, where reclaimed water is intentionally introduced into the raw water supply for the purposes of increasing the total volume of water available for potable use, disinfection to produce reclaimed water having no detectable total coliform organisms per 100 ml is recommended. Total coliform is recommended, in lieu of fecal coliform, to be consistent with the Safe Drinking Water Act (SDWA) National Primary Drinking Water Regulations (NPDWR) that regulate drinking water standards for producing potable drinking water.

These guidelines do not include suggested specific parasite or virus limits. Parasites have not been shown to be a problem at water reuse operations in the U.S. at the treatment and quality limits recommended in these guidelines, although there has been considerable interest in recent years regarding the occurrence and significance of *Giardia* and *Cryptosporidium* in reclaimed water. Viruses are of concern in reclaimed water, but virus limits are not recommended in these guidelines for the following reasons:

A significant body of information exists indicating that viruses are reduced or inactivated to low or immeasurable levels via appropriate wastewater treatment, including filtration and disinfection (Yanko, 1993).

- The identification and enumeration of viruses in wastewater are hampered by relatively low virus recovery rates, the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses.
- The laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes about 14 days, and an additional 14 days are required to identify the viruses.
- While recombinant DNA technology provides new tools to rapidly detect viruses in water (e.g., nucleic acid probes and polymerase chain reaction technology), methods currently in use are not able to quantify viruses or differentiate between infective and non-infective virus particles.
- There is no consensus among virus experts regarding the health significance of low levels of viruses in reclaimed water.
- There have been no documented cases of viral disease resulting from the reuse of wastewater at any of the water reuse operations in the U.S.

The removal of suspended matter is related to the virus issue. Many pathogens are particulate-associated and that particulate matter can shield both bacteria and viruses from disinfectants such as chlorine and UV radiation. Also, organic matter consumes chlorine, thus making less of the disinfectant available for disinfection. There is general agreement that particulate matter should be reduced to low levels, e.g., 2 NTU or 5 mg/l TSS, prior to disinfection to ensure reliable destruction of pathogenic microorganisms during the disinfection process. Suspended solids measurements are typically performed daily on a composite sample and only reflect an average value. Continuously monitored turbidity is superior to daily suspended solids measurements as an aid to treatment operation.

The need to remove organic matter is related to the type of reuse. Some of the adverse effects associated with organic substances are that they are aesthetically displeasing (may be malodorous and impart color), provide food for microorganisms, adversely affect disinfection processes, and consume oxygen. The recommended BOD limit is intended to indicate that the organic matter has been stabilized, is nonputrescible, and has been lowered to levels commensurate with anticipated types of reuse. TSS limits are suggested as a measure of organic and inorganic particulate matter in reclaimed water that has received secondary treatment. The recommended BOD and TSS limits are readily achievable at well operated water reclamation plants.

The suggested setback distances are somewhat subjective. They are intended to protect drinking water supplies from contamination and, where appropriate, to protect humans from exposure to the reclaimed water. While studies indicate the health risk associated with aerosols from spray irrigation sites using reclaimed water is low, the general practice is to limit, through design or operational controls, exposure to aerosols and windblown spray produced from reclaimed water that is not highly disinfected.

Unplanned or incidental indirect potable reuse occurs in many states in the U.S., while planned or intentional indirect potable reuse via groundwater recharge or augmentation of surface supplies is a less-widely accepted practice. Whereas the water quality requirements for nonpotable water uses are tractable and not likely to change significantly in the future, the number of water quality constituents to be monitored in drinking water (and, hence, reclaimed water intended for potable reuse) will increase and quality requirements will become more restrictive. Consequently, it would not be prudent to suggest a complete list of reclaimed water quality limits for all constituents of concern. Some general and specific information is provided in the guidelines to indicate the extensive treatment, water quality, and other requirements that are likely to be imposed where indirect potable reuse is contemplated.

4.3 Pathogens and Emerging Pollutants of Concern (EPOC)

As needs for alternative water supplies grow, reclaimed water will be used more in both direct nonpotable applications and indirect potable reuse projects. Future monitoring for pathogens and other EPOCs will likely be necessary to ensure that reclaimed water is a safe water source. For example, California regulations require monthly sampling and analysis for *Giardia*, enteric viruses, and *Cryptosporidium* for the use of reclaimed water for impoundments during the first year of operation (State of California, 2000). After the first year, the reclaimed water may be sampled and analyzed quarterly and monitoring may be discontinued after 2 years of operation with the approval of the California Department of Health Services (DHS). As previously discussed, Florida requires monitoring of *Giardia* and *Cryptosporidium* with sampling frequency based on treatment plant capacity for specific types of reuse.

The DHS updated the draft regulations for Groundwater Recharge Reuse in July 2003 to require monitoring of EPOCs. Each quarter, during the first year of operation, the reclaimed water shall be analyzed for: unregulated chemicals; priority toxic pollutants; chemicals with state action levels; and other chemicals that the DHS has specified (California DHS, 2003). Chemicals with state action levels are defined as chemicals that have been detected at least once in drinking water supplies or chemicals of interest for some specific reason. The other chemicals as specified by the DHS include N-Nitrosodiethylamine (NDEA) and N-Nitrosopyrrolidine.

The draft regulations also require annual monitoring of pharmaceuticals, endocrine disrupting chemicals, and other chemical indicators of municipal wastewater presence. The draft regulations state that these samples are being collected for information purposes, and there are no standards for the contaminants listed and no standards anticipated at this time (California DHS, 2003).

Although no illnesses to date have been directly connected to the use of reclaimed water, in order to better define pathogens and EPOCs contained in reclaimed water, it is recommended to continue with ongoing research and additional monitoring for *Giardia*, *Cryptosporidium*, and other EPOCs.

4.4 Pilot Testing

Because it is desirable to fully characterize the reclaimed water to be produced and to compare its quality to other water sources in the area, pilot testing should be conducted in support of some of the more sensitive types of reuse, like groundwater recharge by injection and indirect potable reuse. Pilot testing can be used to demonstrate the ability of the selected unit processes to meet project objectives and to refine the design of sophisticated treatment trains. Pilot testing also can be used to demonstrate the ability of the treatment and disinfection units to effectively control pathogens and organic compounds. As part of this activity, the EPOCs, including pharmaceutically active substances, endocrine disrupters, and personal care products, can be evaluated. Ideally, pilot testing should build on previous work as opposed to repeating it.

4.5 References

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CHAPTER 5

Legal and Institutional Issues

Although specific laws vary widely, most states have adopted a number of rules and policies that both support and challenge the development of reclaimed water projects. Since public health regulations are reviewed in detail in Chapter 4, this chapter focuses on other issues that emerge during the various stages of planning and implementing water reuse projects, including relevant rules promulgated by federal, state, and local jurisdictions.

Laws, policies, rules, and regulations that affect project ***planning*** include water rights laws, water use, and wastewater discharge regulations, as well as laws that restrict land use and protect the environment. Included in project ***implementation*** issues are policies that guide the development of reclaimed water rates and agreements between reclaimed water producers, wholesalers, retailers, and customers, as well as rules affecting system construction and liability for water reuse.

Some legal matters are quite technical, and the body of statutory and case law in the area of water reuse is relatively small. The majority of the rules and policies are focused on areas where water reuse has been practiced, and expansion to other areas might raise issues not discussed here. Therefore, managers should carefully consider the legal and institutional aspects of a new reuse project, and obtain counsel to help weigh alternatives and risks. However, even a review of the basic issues should allow reuse planners to identify the most important questions early in the planning process where they can be most effectively addressed.

This section also expands upon the following guidelines that can assist managers in addressing legal and institutional issues during the planning and implementation phases of a reuse system:

- Identifying the legal and institutional drivers for reuse
- Developing a public education program
- Forging and maintaining contact with the appropriate agencies
- Developing a realistic schedule
- Assessing cash flow needs
- Considering institutional structure
- Identifying steps to minimize liability
- Preparing contracts

5.1 Water Rights Law

A water right is a right to use water – it is not a right of ownership. In the U.S., the state generally retains ownership of “natural” or public water within its boundaries, and state statutes, regulations, and case law govern the allocation and administration of the rights of private parties and governmental entities to use such water. A “water right” allows water to be diverted at one or more particular points and a portion of the water to be used for one or more particular purposes. A basic doctrine in water rights law is that harm cannot be rendered upon others who have a claim to the water. Water rights are an especially important issue since the rights allocated by the states can either promote reuse measures, or they can pose an obstacle. For example, in water-limited areas, where water reuse might be most attractive, water rights laws might prohibit the use of potable water for nonpotable purposes, while at the same time restricting the use of reclaimed water in a consumptive fashion that prevents its return to the stream.

State laws allocate water based on 2 types of rights – the appropriative doctrine and the riparian doctrine. These will be described in general terms, after which there will be a brief analysis of their application to water reuse projects.

5.1.1 Appropriative Rights System

The appropriative rights system is found in most western states and in areas that are water-limited. (California has both appropriative and riparian rights.) It is a system by which the right to use water is appropriated – that is, it is assigned or delegated to the consumer. The basic notion is first in time, first in right. In other words, the right derives from beneficial use on a first-come, first-served basis and not from the property's proximity to the water source. The first party to use the water has the most senior claim to that water. The senior users have a continued right to the water, and a "late" user generally cannot diminish the quantity or quality of the water to the senior user. This assures that senior users have adequate water under almost any rainfall conditions, and that later users have some moderate assurance to the water. The last to obtain water rights may be limited to water only during times when it is available (wet season). The right is for a specific quantity of water, but the appropriator may not divert more water than can be used. If the appropriated water is not used, it will be lost.

Generally, appropriative water rights are acquired pursuant to statutory law; thus, there are comprehensive water codes that govern the acquisition and control of the water rights. The acquisition of the water right is usually accompanied by an application to state officials responsible for water rights and granted with a permit or license. The appropriative rights doctrine allows for obtaining water by putting it to beneficial use in accordance with procedures set forth in state statutes and judicial decisions.

The appropriative water rights system is generally used for groundwater throughout the U.S. Water percolating through the ground is controlled by 3 different appropriative methods: absolute ownership, reasonable use rule, or specific use rule. Absolute ownership occurs when the water located directly beneath a property belongs to the property owner to use in any amount, regardless of the effect on the water table of the adjacent land, as long as it is not for a malicious use. The reasonable use rule limits groundwater withdrawal to the quantity necessary for reasonable and beneficial use in connection with the land located above the water. Water cannot be wasted or exported. The specific use rule occurs when water use is restricted to one use.

During times of excess water supply, storage alternatives may be considered as part of the reuse project so that water may be used at a later date. A determination of the ownership or rights to use this stored reclaimed water will need to be made when considering this alternative.

5.1.2 Riparian Rights System

The riparian water rights system is found primarily in the east and in water-abundant areas. The right is based on the proximity to water and is acquired by the purchase of the land. A riparian user is not entitled to make any use of the water that substantially depletes the stream flow or that significantly degrades the quality of the stream. Such riparian use can only be for a legal and beneficial purpose. The right of one riparian owner is generally correlative with the rights of the other riparian owners, with each landowner being assured some water when available.

Water used under a riparian right can be used only on the riparian land and cannot be extended to another property. However, unlike the appropriative doctrine, the right to the unused water can be held indefinitely and without forfeiture. This limits the ability of the water authority to quantify the amount of water that has a hold against it and can lead to water being allocated in excess of that available. This doctrine does not allow for storage of water.

5.1.3 Water Rights and Water Reuse

In arid parts of the western U.S., reclaimed water often constitutes a more reliable supply than rights to surface water or groundwater granted by a water authority. This is particularly true when a user has low-priority rights that are curtailed or withdrawn in times of shortage. (Such subordinate rights are sometimes referred to as "paper water" as opposed to "wet water" which refers to the possession of an actual supply.) Because of the difficulty in obtaining an uninterrupted supply, reclaimed water has simultaneously become an attractive alternative water source and the largest block of unappropriated water in the West. Consequently, it is important to understand who retains control of the reclaimed water among the discharger, water supplier, other appropriators, and environmental interests. For example, in Washington State, the municipal corporation of the City of Walla Walla was taken to court by a local irrigation district that wanted the city to continue to discharge wastewater effluent into Mill Creek, a natural channel, for irrigation use. The court decreed on 2 occasions that the city must discharge all of its wastewater effluent, at all seasons of the year, into the creek (Superior Court of the State of Washington, 1927 and 1971).

According to Colgne and MacLaggan (1995) the downstream water user's right to reclaimed water depends on the state's water allocation system:

Some states issue permits to the owners of reclaimed water or to appropriators of it when discharged into a natural water course. These states granting permits to the appropriators of reclaimed water do so treating such discharges into a reclaimed watercourse as if it has been abandoned and thus available for appropriation. Other states issue appropriation permits containing a provision that clarifies that the permit does not, in itself, give the permittee a right against a party discharging water upstream who may cease to discharge the water to the watercourse in the future.

In other words, state law can either promote or constrain reuse projects depending on how its system of water rights regards the use and return of reclaimed water. In general, the owner of a wastewater treatment plant that produces effluent is generally considered to have first rights to its use and is not usually bound to continue its discharge. However, when a discharger's right to reuse is constrained, such restrictions are usually based on issues resulting from one of the following scenarios:

- Reduced Discharge – Reduction or elimination of effluent discharge flows due to certain types of reuse (e.g. evaporative cooling, groundwater infiltration) could result in legal challenges from downstream users, especially when the reduced flow results in serious economic losses or negative impacts on the environment. When the use of reclaimed water reduces or eliminates the discharge of wastewater to the watercourse, downstream users may make claim damages against the owner of the reuse project. The nature of the legal challenge would depend on the water rights system used. These issues are less well defined for groundwater than for streams and rivers.

- Changes in Point-of-Discharge or Place-of-Use – Occurs in states with appropriative rights where laws are designed to protect the origin of the water by limiting the place-of-use or by requiring the same point of discharge. In riparian states, the place-of-use can also be an issue when reclaimed water is distributed to users located outside the watershed from which the water was originally drawn.

- Hierarchy of Use – Generally with water reuse, the concepts of "reasonable use" and "beneficial use" should not present an obstacle, particularly if such reuse is economically justified. Nevertheless, a hierarchy of use still exists in both riparian and appropriative law, and in times of water shortage, it is possible that a more important use could make claim to reclaimed water that, for example, is being used for industrial process water.

- Reduced Withdrawal – A water reuse program that reduces withdrawals from the water supply will probably pose no third-party conflict with water rights issues, but the impact of such reductions on project-proponent water rights should be evaluated. In some instances, such as when water rights or allocations are based on historic usage, reductions could jeopardize the amount of water a customer is entitled to, especially during times of drought. This has a negative effect on the marketing of reclaimed water. Therefore, where possible, assurances should be made that historic allocations will not be reduced to the point that the customer will suffer damage during periods of shortage.

5.1.4 Federal Water Rights Issues

Although most water rights issues are decided according to state law, in certain cases federal water laws may impact the planning of water reuse projects. This most often occurs when the project augments, reduces, or otherwise impacts the supply of water to more than one state, to protected Native American tribes, or to other countries. In addition to these areas of federal involvement, the federal government also has the right to adequate water from sources on or adjacent to its own property to meet the required needs of the land. Some of the water rights laws that may apply to this situation are listed below.

- Multi-State and Federal Water Allocations – The federal government may claim jurisdiction in disputes between states regarding the allocation of limited water supplies. This has been particularly true in the West where 5 states (Arizona, California, Colorado, Nevada, and Utah) are served by the Colorado River where the flow is not always sufficient to supply all the nominal allocations. A federal interest may also be invoked when water owned by the federal government is allocated to various parties within the same state. In such cases, the federal government may serve as the "honest broker" between parties. Or, in instances were the federal interest is strong enough, the government may support the implementation of an appropriate solution to allocation conflicts by funding recommended improvements. In either situation, the availability of alternative water supplies (e.g. reclaimed water) may constitute an important factor in determining water rights and entitlements. (This is also discussed in

Section 5.2 “Water Supply and Use.”)

- Native American Water Rights – Although there have been many court decisions relating to the water rights of Indian reservations and other federal lands, there is still a great deal of uncertainty as to how these decisions should be interpreted. If there is a possibility that a water reuse project will conflict with the federal reserved water rights, either from an Indian reservation or other federal reserve, a very careful legal interpretation of such water rights should be obtained.

- International Water Rights – Another area of federal interest with respect to water rights is in the distribution of water supplies across state lines, or in international or boundary waters (e.g. the Great Lakes, the Tijuana River). In such situations, where the use of reclaimed water might reduce the access to water supply between states, or to another nation, federal jurisdiction may be imposed.

- Water Rights on Federal Property – Referred to as federal reserved water rights, the quantity of water reserved by the federal government does not have to be established at the time of the land’s acquisition. In addition, these water rights are not lost due to non-use or abandonment and can be designated for purposes other than that which they were originally intended, as long as consumption does not increase. These rights may be set aside by executive order, statute, treaty, or agreement (Weinberg and Allan, 1990). Water may also be appropriated by the federal government for purposes established by Congress and carried out on non-reserved lands. Like the water rights associated with federal reserves, this right to water for non-reserved lands may not cause harm to other water users and the appropriation may not take priority over already existing appropriations. There is some question as to whether there is sufficient legal basis for claiming water under the non-reserved rights scenario.

5.2 Water Supply and Use Regulations

Water supply and use legislation in the context of the *Guidelines* is distinct from water rights law in that it covers policies and regulations, which determine how an agency or entity with water rights may decide to distribute that supply to various parties. Over the past decade, it has become increasingly common for federal, state, and even local entities to set standards for how water may be used as a condition of supplying water to its customers, including the extent to which it must be conserved or reused. Often these standards serve to promote reuse by requiring water users to reduce their total or per capita water use as compared to an established baseline. In some cases, certain uses of potable water (i.e., irrigation, power plant cooling) are considered “unreasonable” and are prohibited unless other, nonpotable sources have been determined to be “environmentally undesirable or economically unsound” (California Water Code Section 13550).

There are 3 main types of water supply and use rules discussed here:

- Water supply reductions

- Water efficiency goals

- Water use restrictions

5.2.1 Water Supply Reductions

Water supply reductions are often imposed during periods of drought. For example, Florida has identified water conservation goals for the water management districts to implement (FDEP, 1999). To meet these goals and to help ensure that enough water is available to meet anticipated potable water demands, Florida issued a water shortage order in 2001 to limit the number of irrigation days per week. Where water shortages are common, cutbacks may be imposed by statute, or they may be written into water allocation agreements between the various parties, (e.g., Colorado River Agreement, Monterey Agreement). During such times, appropriate water rights may be invoked so that the senior rights-holders receive their full allocations, or have their allocations reduced less than those with more junior rights. Whatever the cause, water shortages often provide a powerful incentive to implement water reuse projects to augment supplies, especially where reductions are frequent and other less costly methods (e.g., water conservation) have already been implemented.

When the supply is curtailed by the federal or state government, local water agencies may adopt tiered rates, priority categories, and other pricing and allocation strategies to minimize the impact of drought on customers by making sure that water is available for firefighting, public health, and other critical purposes. One side effect of such restrictions is an increased public awareness of the cost associated with water supply—costs that water reuse projects can help to avoid. The frequency of restrictions can also help planners evaluate the risk of such shortages, which in turn can increase the calculated value of the reuse projects.

5.2.2 Water Efficiency Goals

Water efficiency goals can be either mandatory or voluntary. When voluntary goals (or targets) are promulgated, public support for conservation and reuse are usually stimulated by advertising or outreach campaigns designed to underscore the importance of protecting limited supplies. When mandatory goals are set, however, compliance is related to fees and availability of service. On a local level, the consequences for failing to meet mandatory goals can range from higher use fees (e.g. tiered water rates, surcharges) to termination of service. Where water efficiency is required on a state level, incentives are frequently used to encourage compliance, and meeting certain targets is a prerequisite for qualifying for grants or loans or even for receiving a greater percent of an agency's normal allocation.

When water reuse projects are planned in areas where voluntary or mandatory goals are in place, project managers should be sure that the proposed reuse types qualify as water efficiency measures so that reclaimed water customers can take advantage of the resulting benefits.

5.2.3 Water Use Restrictions

Water use restrictions may either prohibit the use of potable water for certain purposes, or require the use of reclaimed water in place of potable water. Ordinances requiring water reuse, however, generally allow otherwise prohibited and "unreasonable" uses of potable water to occur when reclaimed water is unavailable, is unsuitable for the specific use, is uneconomical, or when its use would have a negative impact on the environment.

On a federal level, there have been discussions in recent years on encouraging the passage of federal water use restrictions as part of a "green building" regulation, such that all federally-sponsored projects must evaluate the use of reclaimed water during the planning process. However, no such rules have yet been proposed. On a state level, water use restrictions are important because they give local jurisdictions a legal foundation for regulating local use. They may also be effective in promoting water reuse, particularly when such rules also require state agencies to evaluate alternative supplies for all state-funded projects.

Local water use restrictions can help to encourage reuse when the practice is generally accepted and readily available at a cost below other supplies. However, an important consideration in evaluating the implementation of such restrictions is deciding what type of penalties or consequences result from non-compliance. In the case of local water restrictions, it may not be necessary to test the enforceability of the statutes, since the potential consequences of non-compliance may be sufficient to persuade most customers to use reclaimed water for appropriate purposes. Otherwise, penalties should be specified at a level adequate to deter violation. Such penalties may include disconnection of service and a fee for reconnection with fines and jail time for major infractions (e.g., Mesa, Arizona and Brevard County, Florida). However, other regulations designed to protect water customers from termination may mitigate or even neutralize that particular penalty option.

Where local ordinances require the use of reclaimed water, they may also include a variety of other requirements regulating its supply and use, including rules for customer connection, inspection, and facility management. Many cities require customers within a given distance of existing or proposed reclaimed water pipes to connect to the reclaimed water system. This may be coupled with restrictions on the use of potable water for nonpotable purposes, such as irrigation. Some cities have gone as far as to prohibit the use of other nonpotable water (i.e. groundwater or surface water) where reclaimed water is available. These rules are examined more closely in a later section, 5.5.3 Customer Agreements.

5.3 Wastewater Regulations

Both federal and state agencies exercise jurisdiction over the quality and quantity of wastewater discharge into public waterways. The primary authority for the regulation of wastewater is the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA) (Public Law 92-500). While the legislative origin of the CWA stretches back to the Rivers and Harbors Act of 1899, the 1972 CWA assigned the federal government specific responsibilities for water quality management designed to make all surface waters "fishable and swimmable" (Cologne and MacLaggan, 1995). The CWA requires states to set water quality standards, thus establishing the right to control pollution from wastewater treatment plants, as long as such regulations are at least as stringent as federal rules. Primary jurisdiction under the CWA is with the EPA, but in most states the CWA is administered and enforced by the state water pollution control agencies.

Wastewater discharge regulations mostly address treated effluent quality—specifically the removal of chemical pollutants and biological pathogens that could have a deleterious effect on receiving waters. Even in regions of the U.S. where rainfall is plentiful (i.e., Florida), regulations that establish criteria for discharged wastewater water quality can provide a powerful incentive to reuse treated effluent. Although less common, discharge permits may also restrict the quantity of effluent discharged to a receiving body to limit its effect on the local ecosystem. Such regulations may be continuous or seasonal, and may or may not correspond to a period when reclaimed water is in demand. As with water quality limits, it is important for those planning reuse projects to meet with treatment plant managers to understand the extent of discharge limitations and how they may be alleviated by supplying treated effluent for reuse.

5.3.1 Effluent Quality Limits

The CWA regulates discharge of pollutants into navigable waters through permits issued pursuant to the National Pollution Discharge Elimination System (NPDES). Under the CWA, the term “navigable waters” means waters of the U.S. The federal courts follow the Tenth Circuit Court’s conclusion that this definition is an expression of congressional intent “to regulate discharges made into every creek, stream, river or body of water that in any way may affect interstate commerce” (United States vs. Earth Sciences Inc., 1979).

The goal of the CWA is to “restore and maintain the chemical, physical and biologic integrity of the nation’s waters.” The CWA sets forth specific goals to conserve water and reduce pollutant discharges and directs the EPA Administrator to assist with the development and implementation of water reclamation plans, which will achieve those goals. Major objectives of the CWA are to eliminate all pollutant discharges into navigable waters, stop discharges of toxic pollutants in toxic amounts, develop waste treatment management plans to control sources of pollutants, and to encourage water reclamation and reuse. Pursuant to this goal, the EPA has evaluated major waterways in the U.S. to determine which ones fail to meet federal water quality standards. Waterbodies listed as “impaired” according to Section 303(d) of the CWA are protected by strict limits on the discharge of the specific pollutants of concern that could further degrade their water quality.

In addition to limits on the concentration of specific contaminants, discharge regulations may also include limits on the total mass of a pollutant discharged to the receiving stream – known as total maximum daily load (TMDL) limits – and on the quality of the water in the receiving stream itself (e.g. minimum dissolved oxygen limits). These regulations are usually the result of extended negotiations between federal, state, and local agencies.

Wastewater discharge regulations are important to water reuse managers for a number of reasons. First, reuse projects can be implemented as an alternative to high levels of treatment when discharge regulations require advanced treatment methods, such as nutrient removal. Second, the level of treatment required by the NPDES permit may be adequate to meet most health regulations, reducing the investment needed to meet reuse standards. By the same token, the level of reliability required by NPDES standards may be less rigorous than what paying customers expect, so that supplementary treatment systems are needed to ensure continuous production. These issues should be thoroughly explored by those planning water reuse projects prior to project design and implementation.

5.3.2 Effluent Flow Limits

Although less common than water quality regulations, the quantity of treatment plant effluent discharged to a receiving body may also be limited by regulation, such as the Endangered Species Act (ESA). Such regulations may be continuous or seasonal, and may or may not correspond to periods associated with reclaimed water demand as required by the NPDES permit. For instance, state regulators in California required the San Jose/Santa Clara Water Pollution Control Plant (serving the Silicon Valley area of northern California) to reuse treated effluent as an alternative to limiting discharge into the south end of San Francisco Bay during the summer dry-weather period (May through October). In this instance the limitation was due not to contaminants, but to the fact that the point of discharge was a saltwater marsh which was made brackish by the discharge of relatively fresh treated effluent. The salt marsh in question is home to 2 endangered species (Rosenblum, 1998). Further discussion of the Endangered Species Act is in Section 5.4.2.

Effluent quantity may also be limited due to the demand for the reclaimed water by communities in the area. In a 1984 decision by the California State Water Resources Control Board, the Fallbrook Sanitary District (a wastewater discharger near San Diego) was enjoined to show cause why their treated effluent was discharged to the Pacific Ocean rather than made available for reuse by the local community. As discussed in the citation above, the foundation of this ruling (which has not been tested by the courts) lies with that state’s prohibition against wasting water and the “unreasonable” use of potable water when reclaimed water is available. This case also illustrates a trend towards viewing water of any quality suitable for some type of reuse, such that its discharge may be limited for the sake of preserving a scarce public resource.

5.4 Safe Drinking Water Act – Source Water Protection

In 1996, the 104th Congress reauthorized and amended Title XIV of the Public Health Services Act (commonly known as the Safe Drinking Water Act). One of the amendments included was Section 132, Source Water Assessment, which requires that the EPA administrator publish guidance for states exercising primary enforcement responsibility for public water systems to carry out directly or through delegation, (for the protection and benefit of public water systems and for the support of monitoring flexibility), a source water assessment program within the state's boundaries. The program requirements include: (a) delineating the boundaries of the assessment areas in such state from which one or more public water systems in the state receive supplies of drinking water, using all reasonably available hydrogeologic information on the sources of the supply and the water flow, recharge, discharge, and any other reliable information deemed necessary to adequately determine such areas; and (b) identifying contaminants regulated under this title for which monitoring is required under this title or any unregulated contaminants which the state has determined may present a threat to public health. To the extent practical, the origins of such contaminants within each delineated area should be determined so that the susceptibility of the public water systems to such contaminants can be decided.

A state may establish a petition program under which a community water system, municipal or local government, or political subdivision of a state may submit a source water quality protection partnership petition requesting state assistance in the development of a voluntary, incentive-based partnership to reduce the presence of drinking water contaminants, and to obtain financial or technical assistance necessary to set up the source water of a community water system. A petition may only address contaminants that are pathogenic organisms for which regulations are established, or for which regulations have been proposed or promulgated and are detected by adequate monitoring methods in the source water at the intake structure or in any community water system collection, treatment storage, or distribution facilities at levels above the maximum contaminant level (MCL), or that are not reliable and consistently below the MCL.

5.5 Land Use and Environmental Regulations

Land use policies regulate the development and use of property which might be served by reclaimed water systems. Unlike water and wastewater laws that are promulgated and enforced by federal and state governments, most land use regulations are developed and enforced by local jurisdictions. But while they are generally considered to be local matters, land use decisions are always made in the context of federal environmental laws and state planning regulations that also influence their determination. The following section reviews the key elements of local land use planning, as well as the underlying environmental regulations and their effect on planning reclaimed water projects.

5.5.1 General and Specific Plans

Most communities in the U.S. engage in some type of structured planning process whereby the local jurisdiction regulates development according to a general plan. A general plan is designed to serve as "a basis for rational decisions regarding a city's or county's long-term physical development [and] embodies public policy relative to the distribution of future land uses, both public and private" (State of California, 1998 and State of Florida, 2002). General plans can be adopted by ordinance and are sometimes reinforced with zoning regulations and similar restrictions. In some states, communities are legally required to adopt these general plans, and projects that significantly deviate from them must be rejected, modified, or permitted by variance.

The cost of extending utilities into undeveloped areas is an important criterion when deciding where to permit development in a community, as is the availability of resources. Even after a general plan is adopted and an area is planned for a particular type of development, developers may be required to prepare specific plans that demonstrate sufficient water supply or wastewater treatment capacity to meet the needs of their developments. Several western states have also adopted laws that require communities to adopt water management plans and identify additional supplies to support new developments. Such rules actually encourage the implementation of reuse projects that reduce the use of limited resources. In chronically water-short or environmentally sensitive areas, use of reclaimed water may even be a prerequisite for new developments.

However, the local planning process can also pose a challenge to reuse projects by subjecting them to the scrutiny of a public that may have many misconceptions about reclaimed water. Federal and state environmental assessment regulations (which are often included in the local planning process) require public notice of published plans and advertised hearings to solicit opinion from all parties potentially affected by the proposed project. It is not unusual at such hearings to hear opposition to the use of reclaimed water for reasons ranging from health effects to growth inducement to environmental justice. These concerns often mask underlying worries about growth or political issues that may be hard to deal with directly. However, unless the specific concerns are thoroughly addressed in the planning process, it is unlikely that the project will proceed to the point that the underlying issues can emerge to be dealt with. Furthermore, failure of a reuse project to conform to general plan guidelines and local requirements will render the project vulnerable to challenge in the courts or to appeal before the regulatory bodies even after the project is approved.

5.5.2 Environmental Regulations

A number of state and federal environmental regulations promote the use of reclaimed water by limiting the amount of water available to communities or restricting the discharge of wastewater into receiving streams. The ESA in particular has been applied to require water users to maintain minimum flows in western rivers to protect the habitat of various species of fish whose survival is threatened by increases in water temperature and restricted access to breeding grounds. Similarly, as noted previously, the provisions of the CWA can impose limits on both the quality and quantity of treated effluent an agency is allowed to discharge. A community with limited water supply or wastewater treatment capabilities has a real incentive to build a reclaimed water project that augments existing sources and reduces discharge.

Broader in scope, the National Environmental Policy Act (NEPA) requires an assessment of environmental impacts for all projects receiving federal funds, and then the mitigation of all significant impacts. Many states also have equivalent rules that mandate environmental assessment and mitigation planning for all projects prior to construction. Combined with other laws that protect biological, scenic, and cultural resources, these laws can result in a *de facto* moratorium on the construction of large-scale water diversions (by dams) that flood the habitat of protected species or inundate pristine canyons or areas of historical significance.

Even where such projects are allowed to go forward, they may be less cost-effective than water reuse projects that provide a comparable supply with fewer and less expensive mitigations. Both federal and state environmental assessment regulations generally require an economic analysis of alternatives, including the “no project” alternative in which nothing is built. A number of guidance documents are available suggesting approaches to evaluating both the costs and benefits of water projects, including water reuse alternatives. It is particularly important when evaluating the economics of reuse projects to consider how reclaimed water serves to augment water supply and divert wastewater from impacted waters, and to include both direct and indirect benefits. The evaluation should include the consideration of preserving a habitat that might be depleted by importing surface water supplies or the avoided cost of mitigating such an impact. A steady stream of research has appeared in the literature during the past decade suggesting appropriate methods of contingent valuation for environmental benefits (Sheikh *et al.*, 1998).

On the other hand, environmental assessment regulations also require the careful assessment of any negative impacts of reclaimed water projects. Examples of common environmental impacts include the visual impact of tanks and reservoirs and the disturbance of underground cultural resources and hazardous materials by underground pipelines. Less common, but equally significant, projects that provide reclaimed water for irrigation over unconfined aquifers are sometimes required to demonstrate that use of nonpotable water will not contribute to the degradation of underlying groundwater. In such cases, mitigation may include a monitoring program or even additional treatment to match groundwater quality. Rules to protect aquifers from infiltration by reclaimed water may also be adopted.

The manager of a reclaimed water project must be familiar with not only the federal and state regulations guiding the environmental assessment process, but also their interpretation by the local jurisdiction. For example, the federal NEPA process requires a public scoping, dissemination of a Notice of Intent, and at least one public meeting preceding the solicitation and consideration of public comments on project impacts and their mitigation. By contrast, the California Environmental Quality Act (CEQA) mandates specific periods during which project information must be published and encourages—but does not require—formal hearings during project review. However, many lead agencies do conduct public hearings on environmental assessment reports, either independently or in the course of their own public planning process (California Department of Water Resources, 2002 and State of Florida, 2002).

Public review requirements have a significant effect on project schedules. In addition to the time required to assemble site information and assess the potential impacts of the project, there are mandatory public review periods that range from 1 to 6 months depending on the nature of the impact and the type of permit required. A comprehensive implementation schedule should be developed and periodically revised, including lengthy review procedures, the timing of any public hearings that must be held, and the time needed to enact any required legislation. It is especially important to identify any permit review procedures and whether they can occur concurrently or must occur consecutively, and in what order.

5.5.2.1 Special Environmental Topics

In addition to the assessment of environmental impacts commonly encountered by construction of all types of water projects, there are some topics of special concern for the evaluation of reuse projects that reflect the safety of reclaimed water use, including growth inducement, environmental justice, and detection of emerging pathogens. Because the project proponent or lead agency must, by law, address all material questions raised during the assessment process, these topics should be considered at some point during project planning—if only to note that they do not apply.

One environmental impact associated with reclaimed water projects is the potential for growth inducement. Indeed, where communities are constrained by a limited water supply, the availability of a reliable source of reclaimed water can allow more growth than might otherwise occur. However, there are many other factors that contribute to the increase in population in an area, and substitution of nonpotable for potable water may only reduce the negative impact a community's existing water use has on the neighboring environment. In any case, the question of growth inducement must be addressed in evaluating the overall impact of reclaimed water projects.

The question of environmental justice may come up during the permitting of water reuse projects. The term "environmental justice" refers to the historic pattern of siting undesirable environmental facilities (e.g. wastewater treatment plants, landfills and transfer stations, solid waste incinerators) in or adjacent to economically depressed neighborhoods, whose populations may have a proportionally large percentage of people of color or ethnic minorities. An environmental justice policy attempts to ensure that all such facilities are distributed equally throughout the community, so that no one segment bears a disproportionate share of the impact. This policy is reinforced by a number of federal rules pertaining to environmental review of federally-funded projects, the ultimate source of which is the constitutional right to equal protection under the law. While it is reasonable to argue that reclaimed water distribution facilities should not be grouped with other more noxious facilities, and that the use of reclaimed water represents a clear benefit to the neighborhoods where it is available, the population at large does not always share this view. The project manager of a water reuse program should discuss project plans with representatives from all affected communities to gauge their sensitivity to this issue, and provide additional information about reclaimed water to help alleviate neighborhood concerns.

5.6 Legal Issues in Implementation

Just as there are many laws and policies that influence the planning and overall design of water reuse projects, their detailed design, construction, and implementation is also governed by a number of rules and regulations. For example, state health departments may require minimum setback distances between potable and nonpotable pipelines (addressed in Chapter 4), while dual distribution facilities at the customer's site may have to be constructed to meet Uniform Plumbing Code standards. Similarly, a value engineering study of the system design may need to be performed in order for the project to qualify for state or federal funding, which may add to the time required for project review and impact the ultimate construction schedule.

Following construction, various parties need to coordinate their efforts to produce, distribute, deliver, and pay for reclaimed water. Each of these parties must be organized to comply with their contractual obligation, with appropriate legal agreements between the parties to clearly spell out and enforce responsibilities. Indeed, there are a range of legal agreements that may be necessary in order for reclaimed water to be delivered to the end customer for reuse.

The following section examines laws and regulations pertaining to ***project construction*** (both system wide and on-site), agreements between water ***wholesalers and retailers***, and ***customer agreements*** to ensure payment and proper handling of reclaimed water by the end user.

5.6.1 Construction Issues

In general, there are 2 types of regulations associated with construction of reuse projects:

1) Rules governing system construction, including large-diameter mains, pump stations, reservoirs, and other appurtenances required to deliver reclaimed water to groups of customers

2) Rules for on-site construction, specifically separation of existing pipelines into potable and

nonpotable systems, or the installation of new reclaimed water pipelines separate from the potable system

As noted in Chapter 4, state health departments often promulgate regulations for both system and on-site construction, but these rules may be administered by county or even local health departments. State agencies may also take the lead in ensuring that project designs meet the requirements for grant funding, but their rules are frequently adopted from existing federal grant or loan programs. Local agencies may adopt their own special rules incorporating state regulations with additional requirements specific to local jurisdictions.

5.6.1.1 System Construction Issues

Chapter 4 includes a detailed analysis of water reuse regulations and design guidelines in various states. These issues are included here only to provide a comprehensive picture of the overall legal context in which reuse projects are developed and built.

Regulations impacting system construction include both rules governing utility construction in general and rules specifically aimed at water reuse projects. Regulations governing general utility construction include requirements to observe and maintain proper easements for pipelines and facilities, local codes with respect to acceptable building materials and construction practices, as well as all applicable contract and labor laws (which is beyond the scope of this chapter). Prior to and during design of any system construction project, the project manager should become familiar with state and local construction regulations and obtain all necessary permits from local agencies, utilities, and other parties so as not to delay project construction.

In addition to these general rules, many states have rules specifically pertaining to the construction of reclaimed water systems. These regulations frequently designate physical separation distances between reclaimed water and potable and wastewater lines, as well as details for pipeline crossings (e.g., nonpotable below potable). Where it is not practical to maintain minimum distances, some states allow construction of nonpotable pipelines adjacent to potable lines provided that they are cased in suitable materials.

From a legal perspective, federal and state grant and loan programs are established by statute and often establish construction-related rules that projects must meet to qualify for funding. Typically these include:

- Formal review of all designs to ensure that they meet professional standards and present the most “cost-effective” solutions to engineering problems. This review often includes value engineering of the project by professionals who were not involved in the original design.

- Institution of a revenue program identifying additional sources of funds to pay for the initial construction. This is especially true when grant funds are provided for construction on a reimbursement basis, to ensure that the project sponsor will be able to afford the project without the support of grant funds.

- Identification of customers, with some evidence that they will individually and collectively use a specific quantity of reclaimed water once it is supplied.

Early in the process, agencies that accept grants or loans should be aware of the requirements of their particular programs with respect to project design and funding.

5.6.1.2 On-site Construction Issues

Like system construction regulations, standards for constructing distribution pipelines on a customer’s site (e.g. irrigation systems) are usually a combination of state regulations and local ordinances specifically regarding the use of reclaimed water. State regulations generally focus on requirements to prevent accidental or intentional cross-connection of potable and nonpotable systems by separating the pipelines, requiring clear identification of nonpotable facilities, and installing backflow prevention devices, where appropriate. Local agencies may adopt individual regulations by ordinance, or they may adopt general regulations like the Uniform Plumbing Code, whose Appendix J includes special rules for installing reclaimed water lines inside buildings where potable water is also served. Once again, the manager of a reuse project should become familiar with all pertinent regulations during the design phase to ensure that the system meets state and local codes. See Chapter 4 for a detailed discussion of regulations that have been adopted in various jurisdictions throughout the U.S.

Once on-site facilities have been constructed, state and local regulations often require that cross-connection tests be performed to ensure complete separation between potable and nonpotable systems. Depending on the quality of the water provided and the type of use, agencies may also restrict the times of use and require periodic inspection and reporting on system operation, even after the on-site system has been installed and approved. This topic is addressed more closely in Section 5.5.3 Customer Agreements.

5.6.2 Wholesaler/Retailer Issues

One of the first steps in implementing a water reuse program is the identification of roles and responsibilities for the production and wholesale and retail distribution of reclaimed water. Many different types of institutional structures can be utilized for implementing a water reuse project and responsibility for reclaimed water production and wholesale and retail distribution can be assigned to different groups depending on their historical roles and technical and managerial expertise (**Table 5-1**).

The various departments and agencies within a government may come into conflict over the proposed reuse system unless steps are taken early in the planning stages to find out who will be involved and to what level. Close internal coordination between departments and branches of local government will be required to ensure a successful reuse program. Obtaining the support of other departments will help to minimize delays caused by interdepartmental conflicts.

A good example of integrated authority is the Irvine Ranch Water District in California, an independent, self-financing entity responsible for all phases of reclaimed water production and distribution. Under its original enabling legislation, the district was strictly a water supply entity; but in 1965, state law was amended to assign it sanitation responsibilities within its service area. This put the district is in a good position to deal directly, as one entity, with conventional potable water and nonpotable water services. Such a position contrasts markedly with other institutional arrangements in the Los Angeles area, where agency relationships are often more complex. For instance, the Pomona Water Reclamation Plant is operated by the Sanitation Districts of Los Angeles County, which sells reclaimed water to several purveyors, including the municipal Pomona Water Department, who then redistributes it to a number of users.

5.6.2.1 Institutional Criteria

In evaluating alternative institutional arrangements, responsible managers should determine the best municipal organizations or departments to operate a reclamation and reuse program. For example, even if the municipal wastewater treatment service is permitted by law to distribute reclaimed water, it might make more sense to organize a reuse system under the water supply agency or under a regional authority (assuming that such an authority can be established under the law).

Among the criteria that should be considered in developing a viable arrangement is the ability of the proposed entity to finance the project and enter into the following types of agreements:

- Financing Power – The agency responsible for financing the project should be able to assume bonded indebtedness, if such financing is likely, a determination should be made as to what kind of debt could be assumed, how much, and how debt must be retired. In addition, the evaluation should include the method for recovering the costs of operating the water reclamation facility and any restrictions placed on them by virtue of the institutional structure, including kinds of accounting practices to be imposed upon the entity.

- Contracting Power – Any constraints on how and with whom services can be contracted should be identified, as well as the method of approving such agreements. For example, if contracts are required with other municipalities, they may have limitations on the nature of the corporate structure or legal au-

Table 5-1. Some Common Institutional Patterns

Type of Institutional Arrangement	Production	Wholesale Distribution	Retail Distribution
Separate Authorities	Wastewater Treatment Agency	Wholesale Water Agency	Retail Water Company
Wholesaler/Retailer System	Wastewater Treatment Agency	Wastewater Treatment Agency	Retail Water Company
Joint Powers Authority (for Production and Distribution only)	Joint Powers Authority	Joint Powers Authority	Retail Water Company
Integrated Production and Distribution	Water/Wastewater Authority	Water/Wastewater Authority	Water/Wastewater Authority

thorization of entities with whom they enter into agreement.

5.6.2.2 Institutional Inventory and Assessment

It is necessary to develop a thorough understanding of which organizations and institutions are concerned with which aspects of a proposed reuse system. This understanding should include an inventory of required permits and agency review requirements prior to construction and operation of the reuse system, economic arrangements, subsidies, groundwater and surface water management policies, and administrative guidelines and issues. The following institutions should be involved or at a minimum, contacted: federal and state/regulatory agencies, administrative and operating organizations, and general units of government.

On occasion there is an overlap of agency jurisdiction. For example, it is possible for one agency to control the water in the upper reaches of a stream and a separate agency to control the water in the lower reaches. Unless these agencies can work together, there may be little hope of a successful project.

One of the best ways to gain the support of other agencies is to make sure that they are involved from the beginning of the project and are kept informed as the project progresses. Any potential conflicts between these agencies should be identified as soon as possible. Clarification on which direction the lead agency should follow will need to be determined. By doing this in the planning stages of the reuse project, delays in implementation may be avoided.

5.6.3 Customer Issues

Finally, a key link in the chain of institutional arrangements required to implement water reclamation projects is the relationship between the water purveyor and the water customer. Again, there are 2 dimensions to this arrangement:

1) The legal requirements established by state and local jurisdictions defining the general responsibilities of the 2 parties to protect the public

2) The specific items of agreement between the parties, including commercial arrangements and operational responsibilities

The legal requirements are usually stipulated in state laws, agency guidelines, and local ordinances designed to ensure that reclaimed water is used safely and with appropriate regard for public health. In fact, the agency responsible for reclaimed water distribution should consider adopting an ordinance requiring customers to meet these standards of performance as a condition of receiving reclaimed water. Or, if that is not appropriate, the agency should encourage the jurisdictions where the customers are located to pass such ordinances. In some cases, the requirements for customer performance have been delegated by the state to the reclaimed water purveyor, who in turn is empowered to delegate them to their customers. For instance, where reclaimed water is still statutorily considered effluent, the agency's permit to discharge wastewater may be delegated by the agency to customers whose reuse sites are legally considered to be distributed outfalls of the reclaimed water, with concomitant responsibilities.

The second group of agreements, those agreements made between parties, are more variable and reflect the specific circumstances of the individual projects and the customers they serve. These include rates and charges, fees, rebates, terms of service, and other special conditions of use between reclaimed water suppliers and customers.

Not all reclaimed water systems require development of a reclaimed water ordinance. This is particularly true where there are a limited number of users. For example, it is not uncommon for a reclaimed water supplier providing service to a small number of large users, such as agriculture or industrial customers, to forego development of a reuse ordinance and rely instead on user agreements. In other instances, such as water intensive activities, a single user may well encumber all of the water available from a given reclaimed water source. Where such conditions exist, it is often more appropriate to deal with the customer through the negotiation of a reclaimed water user agreement. However, all of the customer issues discussed should still be addressed in developing customer agreements.

5.6.3.1 Statutory Customer Responsibilities

Protective measures are required to avoid cross-connection of reclaimed water lines with potable water lines. In the event that these responsibilities are codified in a local ordinance, the ordinance and its provisions should be clearly spelled out in the customer agreement. (Local ordinances may, in turn, reference state regulations on this subject, in which case they should provide specific citations, in addition to general references, for the sake of clarity.)

As noted in Chapter 4, required protections may include the mandatory backflow preventers, use of color-coded pipes for the reclaimed and potable water, and periodic inspection of the system. Inspection is recommended to determine if there are any illegal connections, violations of ordinances, or cross-connections. It is important that the ordinance or agreement state which party is responsible for inspection, under what conditions and with what frequency inspection may be required, as well as the consequences if users refuse to perform or allow inspection (i.e., disconnection of service).

A customer agreement (or the corresponding local ordinance) might also specify the type of irrigation system required in order to receive reclaimed water. This could include the requirements for system design (e.g., a permanent below-ground system) or construction details (e.g., specific pipe materials or appurtenances like quick disconnect fittings on hose bibs used for hand watering). The requirements for an irrigation system timer may also be included.

The customer agreement may also include details on financing on-site construction to separate potable and nonpotable piping systems. It is not uncommon for local agencies to fund all or part of the cost of retrofitting a customer's existing system in order to defray the overall cost of reclaimed water use. In such instances, the agency may provide grant funds to the customer to cover the cost of construction or may even construct the facilities at the agency's expense after obtaining a right-of-entry from the customer. In other cases, the cost of the construction may be covered by reductions in the normal rates over a period of time.

Although not included in a customer agreement, a local ordinance might also define when property owners will be required to connect to the reuse system. Examples include the requirement for turf grass facilities (e.g., parks, golf courses, cemeteries, schools) to connect when the system becomes available, requirements for new developments to connect prior to being inhabited, and requirements for all properties to connect as the reuse system becomes available. These agreements might also specify what equipment is available to the customer and how it can be used. For example, Florida allows hose bibs on the reclaimed water system but they must be placed in below-ground, locking boxes.

Local ordinances may also contain requirements for public education about the reuse project, including information on the hazards of reclaimed water, the requirements for service, the accepted uses, and the penalties for violation. In Cocoa Beach, Florida, reclaimed water applicants must be provided an informative brochure to explain public safety and reuse in accordance with the City's ordinance. A detailed discussion of public information programs is provided in Chapter 7.

5.6.3.2 Terms of Service and Commercial Arrangements

Any reclaimed water connection fees and rates associated with service should be addressed in an appropriate rate ordinance passed by the local jurisdiction. Reclaimed water rate ordinances should be separate from those regulations that control reclaimed water use, and may include an "escalator clause" or other means of providing for regular increases proportional to the cost of potable water in the local area. (See Chapter 6 for a discussion of the development of the financial aspects of water reuse fees and rates).

In addition to these considerations, it is often helpful to establish various other terms of service that are particular to the water reuse program and its customers. For example, the customer agreement may specify a certain level of reliability that may or may not be comparable to that of the potable system. When reclaimed water is used for an essential service, such as fire protection, a high degree of system reliability must be provided. However, if reclaimed water use is limited to irrigation, periodic shortages or service interruption may be tolerable. The reclaimed water supplier may also wish to retain the right to impose water use scheduling as a means of managing shortages or controlling peak system demands.

5.7 Case Studies

5.7.1 Statutory Mandate to Utilize Reclaimed Water: California

Underscoring the fact that potable water resources are strained and in many cases reclaimed water represents the next best supply, some states have integrated reclaimed water into the codes and policies that govern water resources in general. An example of such a case from California is Article 7, Water Reuse from the California Code of Regulations, Section 13550, Legislative Findings and Declarations; Use of Potable Water for Nonpotable Uses Prohibited.

a) The Legislature hereby finds and declares that the use of potable domestic water for nonpotable uses, including, but not limited to, cemeteries, golf courses, parks, highway landscaped areas, and industrial and irrigation uses, is a waste or an unreasonable use of the water within the meaning of Section 2 of Article X of the California Constitution if reclaimed water is available which meets all of the following conditions, as determined by the state board, after notice to any person or entity who may be ordered to use reclaimed water or to cease using potable water and a hearing held pursuant to Article 2 (commencing with Section 648) of Chapter 1.5 of Division 3 of Title 23 of the California Code of Regulations:

(1) The source of reclaimed water is of adequate quality for these uses and is available for these uses. In determining adequate quality, the state board shall consider all relevant factors, including, but not limited to, food and employee safety, and level and types of specific constituents in the reclaimed water affecting these uses, on a user-by-user basis. In addition, the state board shall consider the effect of the use of reclaimed water in lieu of potable water on the generation of hazardous waste and on the quality of wastewater discharges subject to regional, state, or federal permits.

(2) The reclaimed water may be furnished for these uses at a reasonable cost to the user. In determining reasonable cost, the state board shall consider all relevant factors, including, but not limited to, the present and projected costs of supplying, delivering, and treating potable domestic water for these uses and the present and projected costs of supplying and delivering reclaimed water for these uses, and shall find that the cost of supplying the treated reclaimed water is comparable to, or less than, the cost of supplying potable domestic water.

(3) After concurrence with the State Department of Health Services, the use of reclaimed water from the proposed source will not be detrimental to public health.

(4) The use of reclaimed water for these uses will not adversely affect downstream water rights, will not degrade water quality, and is determined not to be injurious to plant life, fish, and wildlife.

b) In making the determination pursuant to subdivision (a), the state board shall consider the impact of the cost and quality of the nonpotable water on each individual user.

c) The state board may require a public agency or person subject to this article to furnish information, which the state board determines to be relevant to making the determination required in subdivision (a).

HISTORY: Added by Stats.1977, c. 1032, p. 3090, Section 1, eff. Sept. 23, 1977. Amended by Stats.1978, c. 380, p. 1205, Section 148; Stats.1978, c. 894, p. 2821, Section 1, eff. Sept. 20, 1978; Stats.1991, c. 553 (A.B.174), Section 1.

5.7.2 Administrative Order to Evaluate Feasibility of Water Reclamation: Fallbrook Sanitary District, Fallbrook, California

In 1984 the California State Water Resources Control Board considered a complaint filed by the Sierra Club to enjoin an unreasonable use of water by a wastewater discharger (California State Water Resources Control Board Order 84-7). At issue was a permit issued by the Board authorizing the Fallbrook Sanitary District to discharge up to 1.6 mgd (6000 m^3/d) of treated wastewater to the ocean. The Sierra Club alleged that under the circumstances, the discharge of the district's wastewater to the ocean, where it cannot be recovered for beneficial use, constitutes a waste of water.

Before a wastewater discharger can be required to reclaim water, a determination must be made whether the particular discharge constitutes a waste or unreasonable use of water. Water Code Section 13550, with its focus on prohibiting the use of potable water for nonpotable applications, provided no guidance to the State Board in this instance. Thus, in making its determination, the State Board sought guidance from the state's constitutional prohibitions on waste and related case law.

In keeping with the case law, which indicates that a reasonable use of water today may be a waste of water at some time in the future, the State Board ordered the district, and all future applicants proposing a discharge of once-used water into the ocean, to evaluate the feasibility of reclaiming its wastewater. The State Board insisted that water reclamation be carefully analyzed as an alternative, or partial alternative, to the discharge of once-used wastewater to the ocean in all water-short areas of the state. In adopting its order, the State Board recognized the requirements were consistent with the Board's authority to conduct investigations and prevent waste of water (California Water Code).

Information provided by Cologne and Maclaggan (1995) "Legal Aspects of Water Reclamation" in Wastewater Reclamation and Reuse.

5.7.3 Reclaimed Water User Agreements Instead of Ordinance: Central Florida

While most reclaimed water systems with multiple users will require the adoption of a reclaimed water ordinance, there may be cases where an ordinance is not required, particularly when there are a limited number of users in the system. An example would include the provision of reclaimed water to several large agricultural users where the need for control extends to only a few parties. In such cases, it may be entirely appropriate to handle the requirements of the supplier and the users through a user agreement.

Orlando, Florida's reclaimed water program (in concert with Orange County, Florida) began with about 20 citrus growers under the Water Conserv II Irrigation Program in 1986. Orlando/Orange County entered into a 20-year agreement with each of the growers, with the agreement specifying the responsibilities of both the supplier and the user. Each of these agreements was identical except for the volume of flow provision. The agreement covered suppliers' contractual requirements including "no cost" provision of reclaimed water, water quality limits, minimum pressures, volume of water and delivery schedules, and indemnity provisions for third party claims. From the users' side, the agreements addressed issues such as requirements to take a certain volume of water, transfer of land allowances, inspection requirements, and buyout provisions if the agreement was terminated prior to the 20 year term. As Orlando's reclaimed system grew, each of the users, either agricultural or commercial, were required to enter into a user agreement. For the commercial users, an agreement was developed similar in some respects to the grower agreement. These commercial agreements evolved over time, but all contained the same basic requirements. For example, each of them stated that the customer would pay the user fee for the reclaimed water when such a rate was established by the City. It was not until 2002 that the City elected to adopt monthly user rates with the growth of the reclaimed system for single-family residences. These rates were implemented shortly after the adoption of a reclaimed water ordinance, which governs all aspects of the reclaimed water system within the city boundaries.

Clearly there are other examples of the need for a user agreement when dealing with a larger customer. Orange County, Florida, provides over 10 mgd (438 l/s) of make-up water from its water reclamation facility to the Curtis Stanton Energy Center. The Curtis Stanton Energy Center, located on the east side of Orlando, is owned by the Orlando Utilities Commission and provides electric power to the greater Orlando area. There are unique aspects to the relationship between these 2 entities with respect to the supply of reclaimed water for cooling purposes including stringent water quality requirements, delivery schedules, fees, and means for handling the blow-down water.

5.7.4 Interagency Agreement Required for Water Reuse: Monterey County Water Recycling Project, Monterey, California

The Monterey County Water Recycling Project (MCWRP) consists of a tertiary water recycling plant and water distribution system. Since beginning operation in the spring of 1998, over 14 billion gallons (53 million m^3) of reclaimed water have been produced for irrigation of food crops such as artichokes, lettuce, cauliflower, celery, and strawberries. The project was designed to reduce seawater intrusion along the northwest portion of Monterey County (California) by using reclaimed water instead of groundwater.

The reclaimed water is supplied by the regional wastewater provider, the Monterey Regional Water Pollution Control Agency (MRWPCA). However, the responsibility for water planning rests with the Monterey County Water Resources Agency (MCWRA). Thus, 2 types of agreements were required. The first was a contract between MRWPCA and MCWRA for the sale, disposition, and operation of MCWRP. The second was a series of ordinances between MCWRA and the growers that governed the providing of water for the end user. The focus of this case study is on the contract between MRWPCA and MCWRA.

The base agreement was signed in 1992 and contained the following key provisions:

A. Project Ownership, Operation, and Maintenance

   - The project will be owned and operated by MRWPCA
   - MRWPCA will be reimbursed for the actual

cost of its operation

- MRWPCA will supply water on a daily basis except for infrequent shut-downs
- Water will be provided in accordance with a specified demand schedule

B. Maintenance of Water Quality

- Water produced will be suitable for irrigation of food crops
- MRWPCA will monitor water quality
- Water Quality Committee, which includes local growers, will be formed

C. Records and Audits

- Accounting system required that allocates project costs
- Annual project audit required

D. Project Repairs and Maintenance

- Reserve for replacement established
- MCWRA will cover uninsured costs

E. Indemnification and Insurance

- Each party will hold each other harmless from damages
- Types and amounts of project insurance are defined

F. Term of Agreement/Dispute Resolution

- Provisions for extension of the Agreement are defined
- Options to cancel/terminate are described
- Requirement to meet and confer in the case of disputes

Three amendments to the agreement have been negotiated in order to clarify the details of the agreement. Overall, this contract has worked well.

5.7.5 Public/Private Partnership to Expand Reuse Program: The City of Orlando, Orange County And The Private Sector – Orlando, Florida

The Orange County National Golf Center (OCNGC) is a unique and innovative public/private partnership formed by Orange County, the City of Orlando, and Team Classic Golf Services, Inc. The Orange County National is one of the largest golf centers in the State of Florida, devoted solely to golf and golf instruction.

The Orange County National Golf Course project represents an expansion of the successful Conserv II reuse program jointly owned and operated by the City of Orlando and Orange County, Florida. (See the case study, 3.8.6 Water Conserv II Chapter 3 for additional details.) The County and City purchased 660 acres (270 hectares) of additional land adjacent to 2 of its original rapid infiltration basins (RIB) sites in the rolling hills of west Orange County, originally intended solely for the construction of new RIBs. Large RIB sites in this area typically consist of a series of basins interspersed across the site with large areas of open land between them. In fact, RIBs typically occupy as little as 15 percent of the site, with the remaining area being available for other uses. Hoping to achieve multiple uses on the new lands, the County commissioned a study to determine the feasibility of building a municipal golf course. The results of the feasibility study were very encouraging, and the County and City agreed to pursue this option with the County acting as the lead-contracting agency.

During a subsequent regulatory and permitting delay in the RIB expansion program, an internationally renowned golf instructor and course developer, Mr. Phil Ritson, approached the Orange County Parks Department and the Orange County Convention Center in search of land to construct a public golf course. After considerable debate, all parties agreed to investigate the feasibility of co-locating RIBs and golf facilities on Conserv II property owned jointly by the City and County.

Project planning for the golf course began in 1991. Using a four-step process, the team completed the following before construction started: (1) a business feasibility plan; (2) a request for interested golf course developers; (3) a leasehold agreement; and (4) a capital-financing plan. Each step was crucial and built on the work of the previous steps.

The business feasibility study showed excess demand for golf and high potential for a golf course development. This analysis, along with the primary environmental concerns, such as protection of on-site wetlands acreage and a preliminary survey of threatened and endangered species, was used to develop a request for business proposals. In September 1993, after the City and County had selected and approved Team Classic Golf Services, Inc. as a partner, the difficult work began – negotiating terms for the long-term lease, securing financing for the deal, and setting up a team which would work to the mutual benefit of all the partners. The major breakthrough in the project came when Team Classic acquired private sector financing totaling $51.5 million. A public/private partnership was established through a 55 year leasehold agreement. Forming a partnership with the municipal government and private sector parties took 6 years from its conceptual and planning stages until the start of construction.

In addition to RIBs, the OCNGC incorporated several other environmental benefits. The site includes a number of isolated wetland areas that had been degraded through lowered water tables and invasion of undesirable plant species. The combined golf course RIB and surface water management system was designed to restore and maintain more desirable water elevations, and the invading plant species were removed and replaced by hand-planted native species appropriate to the wetland type. The site was developed in a low-density layout, leaving natural upland habitat areas between the golf holes.

Today, 54 holes of golf are open along with a 42-acre (17-hectare) practice range and a 9-hole executive course. The facilities also include a 33,000 square-foot (3,070- m^2) clubhouse, 50-room campus lodge, a Pro Studio with 5,000 square feet (465 m^2) of instructional space, and an institute housing classrooms and administrative offices. It is estimated that private sector investment will exceed $100M at completion.

Accessibility has been increased through a multi-tiered fee structure that provides reduced rates to Florida residents and even greater reductions for Orlando and Orange County residents. Rent is paid to the City and County in tiered lease payments tied to time and financial performance of the golf course development. As the golf center is more successful, the lease payments will increase.

University of Florida Institute of Food and Agricultural Sciences (IFAS) is using the site as part of a study, which is co-funded by the County and City. The study is examining the effects of reclaimed water use on golf courses, including the effects of fertilizer and pesticide applications. The study results are being used to develop best management practices for golf courses irrigated with reclaimed water.

5.7.6 Inspection of Reclaimed Water Connections Protect Potable Water Supply:
Pinellas County Utilities, Florida

Few things are more important than a safe, potable water supply. Therefore, cross connection control must be taken seriously and comprehensive inspections are absolutely necessary to ensure the public's health. In addition, state and local ordinances and policies must be thoroughly and uniformly enforced. This has become even more important considering the potential threats to our drinking water.

Pinellas County, Florida, began its Cross Connection Control and Backflow Prevention Program in 1977. Major improvements to the inspection process were implemented in 1994 and 2002. Inspections have uncovered remote hose bibs (to docks, etc.), hidden and/or forgotten valves, and interconnections between the potable and well systems with inexpensive and leaking ball or gate valves.

Pinellas County requires that the reclaimed water connection remain in the locked position and that the irrigation system be separated until the day of inspection. The owner, or their legal representative, must sign an application (see copy following this case study) agreeing to use the reclaimed water for its intended purpose and agreeing to inform future owners of these conditions. Owners must schedule an inspection and are to be present to operate the entire system. First, the inspector verifies that the backflow prevention device is installed on the potable meter. Pinellas County inspectors check all zones for potential cross-connections and overspray into public waters, sidewalks, and roadways. A "dry" run, with the potable source on and the reclaimed source off, is then conducted. This helps to limit the possibility of reclaimed water entering the building. Certainly, it is far less intrusive and more cost-effective than flushing the potable plumbing system if a cross-connection occurs. Then the "wet" run, with the reclaimed water connected and the potable water supply turned off at the meter, begins. This uncovers any remote connections and any cross-connections under the reclaimed pressure. A 1-page report (see copy following this case study) with a "point of disconnect" (POD) sketch is completed by the inspector. A reclaimed water curb marker is glued to the curb indicating that the property has passed the inspection. This information is then entered into a database.

Initially, contractors who are unfamiliar with this process have minor concerns about the length of time for this inspection. A typical, well-prepared residential property

Pinellas County Utilities – STANDARD OPERATING PROCEDURES

FOR RECLAIMED WATER CROSS-CONNECTION INSPECTIONS

1. The Pinellas County Utilities Inspector briefly explains the inspection procedure.

2. The Inspector asks the questions necessary to complete the Reclaimed Water Cross-Connection Inspection form, and records the information on the form.

3. The Inspector checks to see if the reclaimed service line has been connected to the irrigation system and checks to make sure that the reclaimed service valve is locked off.

4. The Inspector walks around the building, checking to make sure that all hose bibbs have water flowing from them, and to see if a pressure relief valve is attached, that all reclaimed valve box covers and exposed pipes located above ground (except risers for bush spray heads) are purple in color from the factory or painted with Pantone Purple 522C (Florida Building Code - Plumbing 608.8; DEP 62-610.469(7)(f)) using light stable colorants, and that all sprinkler heads are attached.

5. The Inspector asks to see the Point of Disconnect (POD) from the potable, well, or other water source.

6. The Inspector starts the Dry Run by having the Contractor or Homeowner operate each of the solenoid valves, one zone at a time, and then checks to see if any other water source is being used for irrigation.

7. The Inspector asks the Contractor or Homeowner to connect the irrigation system to the reclaimed service line, and then unlocks the reclaimed water service valve.

8. The Inspector starts the Wet Run, by opening all hose bibbs and then closing the potable water at the water meter and letting the hose bibbs completely drain. Next, the reclaimed water service valve and the Homeowner’s shut-off valve are opened, and each irrigation zone on the property is run, one zone at a time. When each zone is fully pressurized, the Inspector checks each hose bibb to make sure no water is coming out of them and also checks for over spray.

9. The Inspector turns the potable water back on and then turns off all of the hose bibbs.

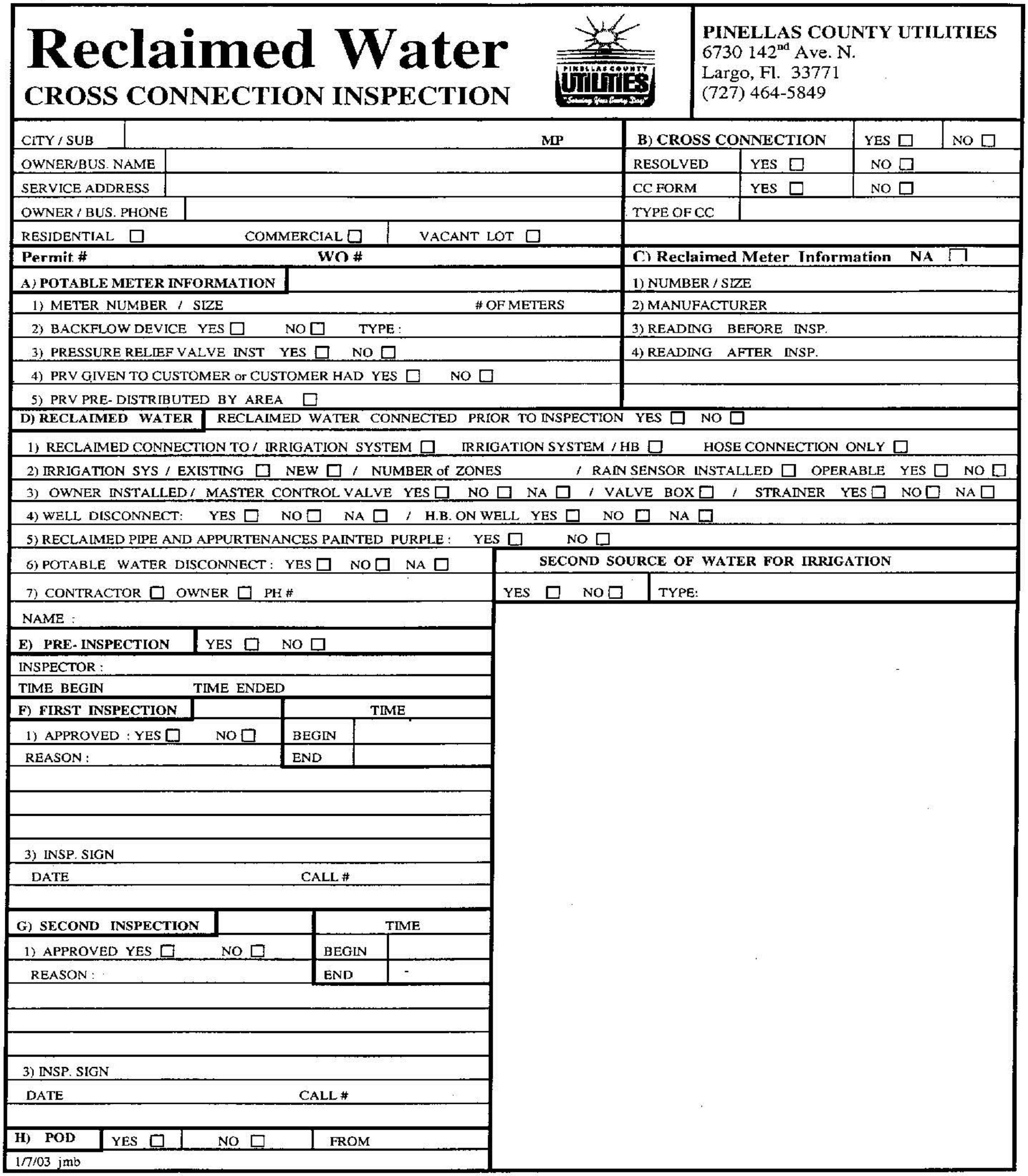
10. The Inspector installs a Reclaimed Water curb marker on the curb or road edge.

11. The Inspector makes a drawing on the form, depicting the locations of buildings, streets, driveways, sidewalks, POD, Pinellas County water meter, and the reclaimed box. Any areas with no irrigation present are identified, and each component of the drawing is labeled. The location of the POD is referenced by measurements taken at right angles to the building’s walls.

12. The Inspector returns to the office and enters the information into the MAXIMO Work Management computer program.

Pinellas County Application for Reclaimed Water Service and Cross-Connection Inspection Forms

As reclaimed water service becomes more common, utilities create the forms required to keep track of customers and address concerns critical to distribution of nonpotable water. The following forms present the application for service and cross-connection inspection forms currently used by the Pinellas County Utilities in Florida.



Reclaimed Water
CROSS CONNECTION INSPECTION

PINELLAS COUNTY UTILITIES
6730 142nd Ave. N.
Largo, Fl. 33771
(727) 464-5849

CITY / SUB MP
OWNER/BUS. NAME
SERVICE ADDRESS
OWNER / BUS. PHONE
RESIDENTIAL ☐ COMMERCIAL ☐ VACANT LOT ☐
Permit # **WO #**

B) CROSS CONNECTION YES ☐ NO ☐
RESOLVED YES ☐ NO ☐
CC FORM YES ☐ NO ☐
TYPE OF CC

A) POTABLE METER INFORMATION
1) METER NUMBER / SIZE # OF METERS
2) BACKFLOW DEVICE YES ☐ NO ☐ TYPE :
3) PRESSURE RELIEF VALVE INST YES ☐ NO ☐
4) PRV GIVEN TO CUSTOMER or CUSTOMER HAD YES ☐ NO ☐
5) PRV PRE- DISTRIBUTED BY AREA ☐

C) Reclaimed Meter Information NA ☐
1) NUMBER / SIZE
2) MANUFACTURER
3) READING BEFORE INSP.
4) READING AFTER INSP.

D) RECLAIMED WATER RECLAIMED WATER CONNECTED PRIOR TO INSPECTION YES ☐ NO ☐
1) RECLAIMED CONNECTION TO / IRRIGATION SYSTEM ☐ IRRIGATION SYSTEM / HB ☐ HOSE CONNECTION ONLY ☐
2) IRRIGATION SYS / EXISTING ☐ NEW ☐ / NUMBER of ZONES / RAIN SENSOR INSTALLED ☐ OPERABLE YES ☐ NO ☐
3) OWNER INSTALLED / MASTER CONTROL VALVE YES ☐ NO ☐ NA ☐ / VALVE BOX ☐ / STRAINER YES ☐ NO ☐ NA ☐
4) WELL DISCONNECT: YES ☐ NO ☐ NA ☐ / H.B. ON WELL YES ☐ NO ☐ NA ☐
5) RECLAIMED PIPE AND APPURTENANCES PAINTED PURPLE : YES ☐ NO ☐
6) POTABLE WATER DISCONNECT : YES ☐ NO ☐ NA ☐
7) CONTRACTOR ☐ OWNER ☐ PH #
NAME :

SECOND SOURCE OF WATER FOR IRRIGATION
YES ☐ NO ☐ TYPE:

E) PRE- INSPECTION YES ☐ NO ☐
INSPECTOR :
TIME BEGIN TIME ENDED

F) FIRST INSPECTION TIME
1) APPROVED : YES ☐ NO ☐ BEGIN
REASON : END
3) INSP. SIGN
DATE CALL #

G) SECOND INSPECTION TIME
1) APPROVED YES ☐ NO ☐ BEGIN
REASON : END
3) INSP. SIGN
DATE CALL #

H) POD YES ☐ NO ☐ FROM

1/7/03 jmb

PINELLAS COUNTY UTILITIES
Application for Reclaimed Water Service

☐ **Residential**

☐ **Commercial**

For Commercial Properties, a completed Irrigation Area Worksheet is required with this Application for Reclaimed Water

Owner's Full Name and Service Address Please Print in Ink	Mailing Address (If different than service address) Please Print in Ink
Daytime Phone: ( )	**Daytime Phone: ( )**

Do you have an existing irrigation system? ☐ Yes ☐ No
If yes, what is your irrigation supply? ☐ Well ☐ County supplied drinking water ☐ Surface water
What type of connection do you require? ☐ Irrigation system ☐ Hose connection

I, the Applicant, have read and understand the County's Policies, Procedures and Regulations for Reclaimed Water Service and agree to use reclaimed water for the purpose(s) described therein.

Upon transfer of owner or resident I will inform the new owner or tenants that the property is connected to Reclaimed Water.

It is further agreed that the County or Pinellas County Public Health Unit shall have the right to enter the above premises to inspect the reclaimed water piping and fittings: to discontinue County reclaimed water service, for tampering with the service (includes meter and appurtenances), for cross-connections with another service or water source, or for any other reason that may be detrimental to Pinellas County Utilities.

Terms of Application Accepted:

____
Print Name

____
Signature Date

Send Completed Application To:
Pinellas County Utilities
Attn: Customer Service
14 S. Ft Harrison Ave.
Clearwater, FL 33756

PLEASE RETURN ENTIRE THREE-PART APPLICATION
Your copy (with a Utilities Agent's signature) will be mailed to you

For Office Use Only

Account Number:____________________________________

Account Number:____________________________________

Received by: ______________________________ Date: __________________
(Utilities Agent)

PARCEL #:______/______/______/______/______/______
SECTION TOWNSHIP RANGE SUB. NO. BLOCK LOT

inspection is completed in 45 to 60 minutes. Approximately 8,000 inspections have been conducted and contractors work successfully with the County's experienced inspectors.

Information provided by the Pinellas County Utilities Department – Cross-Connection Control and Backflow Prevention Program, 1998, Clearwater, Florida.

5.7.7 Oneida Indian Nation/Municipal/State Coordination Leads to Effluent Reuse: Oneida Nation, New York

The Oneida Indian Nation is in a period of strong economic growth. The cornerstone of its economic development is the Turning Stone Casino Resort, the only casino in New York State. The casino and other Nation enterprises are located in an area of central New York with limited water resources. The viability of future enterprise development is linked to the Nation's ability to adequately meet its water supply and wastewater treatment needs. For the Nation's planned golf course complex, reclaimed water has been identified as a viable water resource for irrigation water. Implementing water reclamation required inter-governmental cooperation between the Nation and the reclaimed water supplier, the City of Oneida. Regulatory or jurisdictional cooperation between the New York State Department of Environmental Conservation (NYSDEC) and the Nation also was required because the Nation, being sovereign, is free to establish its own environmental standards for its lands, while the City is regulated by the NYSDEC. The project was further complicated by the fact that the NYSDEC does not have reclaimed water quality or treatment standards for unrestricted reuse.

An estimate of the peak irrigation demand for the Nation's proposed golf course complex is 670,000 gpd (2540 m^3/d), which is well in excess of the potable water allocation available to the Nation (150,000-250,000 gpd, 570-950 m^3/d). Investigation of the area's water resources identified the City of Oneida's wastewater treatment plant as a water source. The City subsequently agreed to support the Nation's concept for a water reclamation project.

Reclaimed water use is not a common practice in New York State. In fact, the state does not have reclaimed water quality or treatment standards for either restricted or unrestricted urban reuse. In the initial stages of the project, a stakeholders meeting was held with representatives of the Nation, the City, and the NYSDEC. The environmental benefits of the project were discussed at this meeting – the reuse of a water resource, the conservation of existing potable water supplies, and reduced pollutant loads into Oneida Creek and, ultimately, Oneida Lake, which is part of the Great Lakes watershed. The Nation also made its position clear that the NYSDEC had no jurisdiction over activities on Nation land. The NYSDEC concurred with the Nation and City's reclaimed project concept plan, and expressed its basic support of the project. It outlined for the Nation and the City the regulatory framework and procedural steps for expediting the project.

To formally commit the City to the project, the City Council and Mayor needed to pass a resolution to authorize the technical staff of its Public Works Department to proceed with the project. The project team elected to use one of the City's semi-monthly council meetings as the forum to present the benefits of the project. Informational fact sheets were prepared for the meeting, which described in simple terms what reclaimed water is, the current uses of reclaimed water by other communities, and the environmental benefits of reclaiming highly treated wastewater. The fact sheets were distributed before the meeting so that elected officials, the public, and the news media could prepare questions before the council meeting. Factual and candid information was presented on water reclamation – its need in the overall growth plans of the Nation, its environmental benefits and, through its use, the conservation of limited potable water supplies. The City Council unanimously approved a resolution pledging the City's support and commitment to cooperate with the Nation on this project.

The implementation phase of the project included the following major milestones:

- Preparing a draft reuse agreement between the Nation and the City
- Completing the State Environmental Quality Review (SEQR) process to demonstrate the project's environmental benefits and lack of significant negative impacts
- Obtaining approval from the NYSDEC for a State Pollutant Discharge Elimination System (SPDES) permit modification to allow the city to deliver its treated water to the Nation's irrigation pond
- Completing a preliminary design of the project.

Each of these project aspects is discussed below:

Reuse Agreement – The agreement addresses reclaimed water quality and characteristics. The City of Oneida will be responsible for delivering to the Nation reclaimed water of sufficient quality to meet the requirements of the City's SPDES permit and target water quality conditions identified in the reuse agreement. While the entire cost of constructing the project will be borne by the Nation, the planned treatment and pumping systems will be installed at the City's wastewater treatment plant site. The City will be responsible for operating the reclaimed water system. As needed, the Nation will contract with a third party for major maintenance and repair work for the facilities and pipeline.

Other provisions of the agreement include easement and usage rights to allow the City access to Nation land to operate and monitor the reclaimed system, standard conditions regarding good faith commitments, a limited waiver of sovereign immunity for the purpose of implementing and enforcing the agreement, indemnification, notices, and amendments and assignments.

SEQR Review Process – The first step in the SEQR process was for the City to formally request "lead agency" status. This required sending a letter of notice, along with a basic project description, to the potentially interested agencies (including NYSDEC, County Departments of Health, EPA, Army Corps of Engineers, and New York State Department of Transportation). After a required 30-day public comment period, during which no other agency challenged the City's lead agency request, the City became lead agency for SEQR purposes.

An environmental assessment of the project was completed and resulted in a recommendation to the City Council that a "negative declaration" (akin to the "finding of no significant impact" under NEPA) be declared. As an "unlisted action," the project's SEQR conclusion did not need any additional public comment period after the City's negative declaration.

SPDES Permit Modification – To deliver water to an outfall location other than its permitted discharge point (Oneida Creek), the NYSDEC required that the City complete a SPDES permit modification request. Currently, the permit application is under review by the NYSDEC. It is anticipated that the City will obtain the permit modification with few exceptions to the proposed plan. Early involvement and open communication with the NYSDEC was a key success factor in preparing the application based on specific guidance form the NYSDEC.

Preliminary Design – The design report addressed the preliminary design criteria and basis of design for the needed reclaimed water system components, including operation and control strategies. The system design includes a provision that would allow the City to process a portion of its secondary treated effluent through the reclaimed system filter (i.e., providing tertiary treatment) for discharge to the creek outfall in the event there is no demand for reclaimed water. This provision would allow the City to discharge a higher quality water to the creek, but it would not obligate the City to provide a higher level of treatment than is now required by its existing permit. This provision is a secondary benefit, not the driving force behind the project or future permit requirements.

In New York State, where water reclamation is not commonly practiced, the Nation, the City of Oneida, the NYSDEC and other local agencies collaborated in an inter-governmental and multi-jurisdictional effort to make this project possible. A key reason for the successful collaboration was effective communication among all project stakeholders. All involved parties shared the conviction that the project was a win-win proposition for the Nation, the City, and the environment. Early, two-way communication that consistently focused on the project's benefits resulted in full and unanimous support of the project at each of the legal decision-making junctions.

5.7.8 Implementing Massachusetts' First Golf Course Irrigation System Utilizing Reclaimed Water: Yarmouth, Massachusetts

For the first time in the Commonwealth of Massachusetts, reclaimed water is being used as the source water to irrigate a golf course – The Links at Bayberry Hills, which is owned and operated by the Town of Yarmouth. This project required a team effort on the part of everyone involved and many years to successfully implement.

The town developed a landfill closure/reuse plan that provided for a 9-hole expansion of the adjacent town-owned Bayberry Hills Golf Course with 7 of the 9 holes located over the capped landfill. However, since the town already needed additional drinking water supplies to handle peak summer demands in this tourist community, in the spring of 1996, the town began discussions with the Department of Environmental Protection (DEP) about utilizing the effluent from the adjacent Yarmouth-Dennis Septage Treatment Plant (STP) as the source of irrigation water.

The Yarmouth-Dennis STP had an existing biological treatment process followed by sand filtration and ultraviolet (UV) light disinfection. The original facility was not designed to meet stringent reclaimed water standards. After evaluating several options it was determined that the installation of an ozone treatment system prior to filtration was the most efficient option to meet the proposed standards.

A reclaimed water sampling plan was developed in discussions with the DEP. A two-phase sampling program was required. The phase 1 preliminary sampling program was performed in conjunction with the start-up of the new ozone treatment system and consisted of daily fecal coliform testing and continuous turbidity monitoring of the final effluent form the UV channel. Results of the sampling indicated that the proposed fecal coliform and turbidity standards could be attained. The phase 2 program consisted of comparing the results of influent septage samples from the equalization tanks and final effluent samples from the UV channel for the following parameters: Enteric Viruses, *Giardia* and *Cryptosporidium,* Heterotrophic Plate Counts (HPC), Coliphage (Male-specific and Somatic), and *Clostridium perfingens*. Results for these parameters indicated similar log removals with and without the ozone treatment.

Development of Groundwater Discharge Permit to Use Reclaimed Water

The sampling programs were developed to convince DEP that utilizing reclaimed water in Yarmouth was viable and that the interim guidelines could be attained. However, there were several steps necessary to acquire the revised groundwater discharge permit for the project. In total, it took 4 years to acquire the permit that finally allowed the reclaimed water to be utilized. The first step, which began in 1996, involved working closely with the DEP to develop a means for permitting this type of facility; Massachusetts was one of the remaining states that did not have guidelines or regulations for permitting reclaimed water facilities. Ultimately, DEP issued a set of “Interim Guidelines on Reclaimed Water” in May 1999 (Revised January 2000). These guidelines provided a mechanism for permitting reclaimed water projects under the DEP’s groundwater discharge permit regulations.

A site hearing process allowed for a public comment period regarding modifications to the existing Yarmouth-Dennis STP groundwater discharge permit so that it would include the reclaimed water and new application site. Based on all the work that had been done leading up to these events, there were very few comments received and the new groundwater discharge permit was issued on June 28, 2000.

DEP added some additional monitoring parameters to the reclaimed water portion of the permit to help develop a historical database of viral and pathogenic values. The MS2 Coliphage, a viral indicator, will be sampled twice per month for the March through November use period, and can be tested using a fairly inexpensive means.

Giardia, Cryptosporidium, and *Clostridium perfringens* will be sampled 4 times during the use period, which involves expensive testing procedures that take weeks to conduct. Although the reclaimed water is not to be ingested, it is believed that DEP will utilize this data in the future to develop an even greater confidence level that the current stringent reclaimed water standards are protective of public health.

Groundwater Protection Management Plan

Because of the unique way in which the reclaimed water portion of the groundwater discharge permit was written, the implementation of reclaimed water requires close coordination between the treatment plant staff and the golf course staff. Therefore, a Groundwater Protection Management Plan was developed to address these coordination issues. The overall purpose of the plan is to protect the area groundwater. To achieve that purpose, the plan provides an understanding of the issues involved and defines the responsibilities of the various parties. The treatment plant staff are responsible for the groundwater discharge permit compliance, which includes the reclaimed water applied as well as the water collected in the underflow from the golf course. The golf course staff are responsible for the operation and maintenance of the Links at Bayberry Hills. Thus, without close coordination between the 2 parties, permit compliance would be difficult.

Based on the coordination requirements and the uniqueness of this golf course, there were 4 basic elements addressed within the Groundwater Protection Management Plan. The first element deals with the schedule for using the reclaimed water. Town water will be used during the spring months when the golf course staff will be “waking the course up” with different fertilizer applications depending on the previous winter weather conditions. This is also a period when the town can use its own potable water supply. However, in the summer months, when town water supplies are stretched, reclaimed water will be used on the golf course. It is anticipated this will occur beginning in July and will continue until November, or until the reclaimed water supplies of up to 21 million gallons by permit are depleted.

The second element deals with the requirement for the use of slow release fertilizers. The third element deals with the need to reduce the quantity of commercially-applied fertilizer when reclaimed water is in use. The fourth element addresses the coordination between the treatment plant staff and the golf course staff so that the above 3 elements are being done. Thus, an approval form requiring the signature of both parties has been developed for use prior to any fertilizer application on the golf course.

It is believed that the Groundwater Protection Management Plan addresses the key issues between the treatment plant staff and the golf course staff so that, over time, as personnel change, the Town of Yarmouth will have an adequately maintained golf course and adequately protected groundwater supplies. It will also provide the ability to comply with the reclaimed water permit limits. Implementation of the reclaimed water project for the Town of Yarmouth has been a challenge for all parties involved due to its innovative nature for the Commonwealth of Massachusetts. However, all parties worked together to find a way to get this project implemented without compromising public health issues.

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CHAPTER 6

Funding Water Reuse Systems

Like the development of other utilities, the implementation of reuse facilities generally requires a substantial capital expense. Capital improvements at the wastewater treatment facility are normally required, but transmission lines can also add significantly to capital costs. In an urban setting, reuse lines must often be added to the existing transmission infrastructure, requiring careful construction processes. And unless agricultural, industrial, and recreational reuse sites are close to reclaimed water sources, these sites will require new transmission facilities as well.

In addition to the capital costs associated with reclaimed water facilities, there are also additional operation, maintenance, and replacement (OM& R) costs, including those associated with power and water quality monitoring, as well as administrative costs, such as customer billing. And, in almost all cases, implementation of a reuse system involves enhanced cross-connection programs with an associated increase in cost. These costs are typically calculated into a reclaimed water rate, expressed either as a gallonage charge or a fixed monthly fee. Even in situations where reclaimed water systems are developed in response to effluent disposal needs and customers are encouraged to make use of an “unlimited” supply at little to no charge, provisions should still be made for the day when conservation of the reclaimed water supply will be required. Another factor impacting costs is the potential drop in revenues associated with a reduction in potable water use after implementation of a reuse system. This loss of revenue can be particularly challenging if the water and wastewater systems are owned by different utilities. Consequently, multiple financial alternatives should be investigated to fund a reclaimed water system.

6.1 Decision Making Tools

To clarify the issues to be discussed, some general terms are defined as follows:

- Cost-Effectiveness – the analysis of alternatives using an effectiveness scale as a measurement concept. EPA formulated “Cost-Effectiveness Analysis Guidelines” as part of its Federal Water Pollution Control Act (40 CFR Part 35, Subpart E, Appendix A). This technique requires the establishment of a single base criterion for evaluation, such as annual water production of a specific quality expressed as an increase in supply or decrease in demand. Alternatives are ranked according to their ability to produce the same result. The alternatives can include such factors as their impact on quality of life, environmental effects, etc. which are not factored into a cost/benefit analysis.

- Cost/Benefit – the relationship between the cost of resources and the benefits expected to be realized using a discounted cash-flow technique. Non-monetary issues are not factored into these calculations.

- Financial Feasibility – the ability to finance both the capital costs and OM&R costs through locally raised funds. Examples of revenue sources include user fees, bonds, taxes, grants, and general utility operating revenues.

In the context of these definitions, the first analysis to be performed when considering a reuse system would be a cost-effectiveness analysis. This involves analyzing the relevant costs and benefits of providing additional water from fresh water sources versus reclaimed water.

Benefits that can be considered include:

- Environmental - the reduction of nutrient-rich effluent discharges to surface waters

    - the conservation of fresh water supplies
    - reduction of saltwater intrusion

- Economic - delay in or avoidance of expanding existing water supply and treatment facilities

- Delay in, or elimination of, enhancements to the existing potable water treatment systems

- Delay in, or elimination of, enhancements to the existing wastewater treatment systems

Shared benefits should also be considered. For instance, if a benefit is received by water customers from a delay in expanding the water supply (deferred rate increase), a portion of reclaimed water costs could be shared by existing and future water customers. A similar analysis can also be made for wastewater customers who benefit from a delay in, or elimination of, increased levels of treatment associated with more stringent discharge limits.

The cost/benefit analyses are conducted once feasible alternatives are selected. The emphasis of these analyses is on defining the economic impact of the project on various classes of users, (e.g., industrial, commercial, residential, agricultural). The importance of this step is that it relates the marketability of reuse relative to alternative sources, based on the end use. To elaborate, given the cost of supplying reclaimed water versus fresh water for urban use, what is the relationship of water demand to price, given both abundant and scarce resources? The present worth value of the benefits are compared to determine whether the project is economically justified and/or feasible. As part of meeting a requirement to secure a 100-year water supply, an expansion of the reuse system was found to be more cost-effective than traditional effluent disposal coupled with increasing water supplies (Gray *et al.,* 1996).

Finally, financial feasibility determines whether sufficient financial resources can be generated to construct and operate the required reclamation facilities. Specific financial resources available will be explained in subsections 6.2, 6.3, and 6.4.

6.2 Externally Generated Funding Alternatives

It is difficult to create a totally self-supporting reuse program financed solely by reclaimed water user fees. To satisfy the capital requirements for implementation of a reuse program, the majority of the construction and related capital costs are often financed through long-term water and wastewater revenue bonds, which spread the cost over multiple decades. Supplemental funds may be provided by grants, developer contributions, etc., to mitigate or offset the annual revenue requirement. The various externally generated capital funding source alternatives include:

- Local Government Tax-Exempt Bonds – The total capital cost of construction activities for a reuse project could be financed from the sale of long-term (20-30 year) bonds.

- Grants and State Revolving Fund (SRF) Programs – Capital needs could be funded partially through state or local grants programs or through SRF loans, particularly those programs designed specifically to support reuse.

- Capital Contribution – At times, there are special agreements reached with developers or industrial users, requiring the contribution of either assets or money to offset the costs of a particular project.

6.2.1 Local Government Tax-Exempt Bonds

A major source of capital financing for local governments is to assume debt – that is, to borrow money by selling municipal bonds, which enables the municipality to spread the cost of the project over many years. This approach reduces the annual amount that must be raised as compared to funding the entire capital project on a “pay-as-you-go” basis from rate revenues. With many water reclamation projects, local community support will be required to finance the project. If revenue bond financing is used, this matches the revenue stream from the use of reclaimed facilities with the costs of the debt used for construction, but does not normally require voter approval. However, voter approval may be required for general obligation bonds. The types of bonds commonly used for financing public works projects are:

- General Obligation Bonds – Repaid through collected general property taxes or service charge revenues, and generally require a referendum vote. Underlying credit support is the full faith taxation power of the issuing entity.

- Special Assessment Bonds – Repaid from the receipts of special benefit assessments to properties (and in most cases, backed by property liens if not paid by property owners). Underlying credit support is the property tax liens on the specially benefited properties.

- Revenue Bonds – Repaid through user fees and service charges derived from operating reuse facilities (useful in regional or sub-regional projects because revenues can be collected from outside the geographical limits of the borrower). Underlying credit support is the pledged revenues, such as user fees or special charges.

- Short-Term Notes – Usually repaid through general obligation or revenue bonds. These are typically used as a method of construction or interim financing until they can be incorporated into the long-term debt.

The local government must substantiate projections of the required capital outlay, of the anticipated OM&R costs, of the revenue-generating activities (i.e., the user charge system, etc.), and of the "coverage" anticipated – that is, the extent to which anticipated revenues will more than cover the anticipated capital and OM&R costs. A local government finance director, underwriter, or financial advisor can describe the requirements to justify the technical and economic feasibility of the reuse project. Since reuse facilities are often operated as part of a water and wastewater utility fund, bonds issued will probably be issued by the combined utility and thus any financial information presented will be for a combined enterprise fund. The reuse operation will most likely not have to stand alone as a self-sufficient operation and will appear financially stronger.

6.2.2 State and Federal Financial Assistance

Where available, grant programs are an attractive funding source, but require that the proposed system meets grant eligibility requirements. These programs reduce the total capital cost borne by system beneficiaries thus improving the affordability and viability of the project. Some funding agencies have an increasingly active role in facilitating water reuse projects. In addition, many funding agencies are receiving a clear legislative and executive mandate to encourage water reuse in support of water conservation.

To be financially successful over time, a reuse program, however, must be able to "pay for itself." While grant funds may underwrite portions of the capital improvements necessary in a reuse project – and in a few states, state-supported subsidies can also help a program to establish itself in early years of operation – grant funds should not be expanded for funding needs associated with annual operating costs. In fact, most federally- funded grant and loan programs explicitly prohibit the funding of OM&R costs. Once the project is underway, the program should strive to achieve self-sufficiency as quickly as possible – meeting OM&R costs and debt service requirements of the local share of capital costs by generating an adequate stream of revenues through local sources.

6.2.2.1 State Revolving Fund

The SRF is a financial assistance program established and managed by the states under general EPA guidance and regulations and funded jointly by the federal government (80 percent) and state matching money (20 percent). It is designed to provide financial assistance to local agencies to construct water pollution control facilities and to implement non-point source, groundwater, and estuary management activities, as well as potable water facilities.

Under SRF, states make low-interest loans to local agencies. Interest rates are set by the states and must be below current market rates and may be as low as 0 percent. The amount of such loans may be up to 100 percent of the cost of eligible facilities. Loan repayments must begin within 1 year after completion of the facility and must be completely amortized in 20 years. Repayments are deposited back into the SRF to be loaned to other agencies. The cash balance in the SRF may be invested to earn interest, which must accrue to the SRF.

States may establish eligibility criteria within the broad limits of the Clean Water State Revolving Fund (CWSRF). Basic eligible facilities include secondary and advanced treatment plants, pump stations, and force mains needed to achieve and maintain NPDES permit limits. States may also allow for eligible collection sewers, combined sewer overflow correction, stormwater facilities, and the purchase of land that is a functional part of the treatment process.

Water conservation and reuse projects eligible under the Drinking Water State Revolving Fund (DWSRF) include installation of meters, installation or retrofit of water efficient devices such as plumbing fixtures and appliances, implementation of incentive programs to conserve water (e.g., rebates, tax breaks, vouchers, conservation rate structures), and installation of dual-pipe distribution systems as a means of lowering costs of treating water to potable standards.

In addition to providing loans to water systems for water conservation and reuse, states can use their DWSRF set-aside funds to promote water efficiency through activities such as: development of water conservation plans, technical assistance to systems on how to conserve water (e.g., water audits, leak detection, rate structure consultation), development and implementation of ordinances or regulations to conserve water, drought monitoring, and development and implementation of incentive programs or public education programs on conservation.

States select projects for funding based on a priority system, which is developed annually and must be subjected to public review. Such priority systems are typically structured to achieve the policy goals of the state and may range from “readiness to proceed” to very specific water quality or geographic area objectives. Each state was allowed to write its own program regulations for SRF funding, driven by its own objectives. Some states, such as Virginia, provide assistance based on assessing the community’s economic health, with poorer areas being more heavily subsidized with lower interest loans.

Further information on the SRF program is available from each state’s water pollution control agency.

6.2.2.2 Federal Policy

The Clean Water Act of 1977, as amended, supports water reuse projects through the following provisions:

- Section 201 of PL 92-500 was amended to ensure that municipalities are eligible for “201” funding only if they have “fully studied and evaluated” techniques for “reclaiming and reuse of water.” A 201 facility plan study must be completed to qualify for state revolving loan funds.

- Section 214 stipulates that the EPA administrator “shall develop and operate a continuing program of public information and education on water reclamation and reuse of wastewater. . .”

- Section 313, which describes pollution control activities at federal facilities, was amended to ensure that wastewater treatment facilities will utilize “recycle and reuse techniques: if estimated life-cycle costs for such techniques are within 15 percent of the most cost-effective alternative.”

6.2.2.3 Other Federal Sources

There are a number of federal sources that might be used to generate funds for a water reuse project. While there are many funding sources, only certain types of applicants or projects are eligible for assistance under each program.

The U.S. Department of Agriculture (USDA) has several programs that may provide financial assistance for water reuse projects in rural areas, but the definition of a rural area varies depending upon the statutory language authorizing the program. Most of these programs are administered through the USDA Rural Development Office in each state.

Rural Utilities Service (RUS) offers funds through the Water and Waste Program, in the form of loans, grants, and loan guarantees. The largest is the Water and Waste Loan and Grant Program, with approximately $1.5 billion available nationwide per year. This program offers financial assistance to public bodies, eligible not-for-profits and recognized tribal entities for development (including construction and non-construction costs) of water and wastewater infrastructure. Unincorporated areas are typically eligible, as are communities with less than 10,000 people. Grants may be available to communities meeting income limits to bring user rates down to a level that is reasonable for the serviced population. Interest rates for loan assistance depend on income levels in the served areas as well. The Rural Development offices act to oversee the RUS-funded projects from initial application until the operational stage.

Other Rural Development programs are offered by the Rural Housing Service and the Rural Business-Cooperative Service. Rural Housing Service offers the Community Facilities Program that may fund a variety of projects for public bodies, eligible not-for-profits, and recognized tribal entities where the project serves the community. This includes utility projects and may potentially include a water reuse project, if proper justification is provided. The Rural Business-Cooperative Service offers the Rural Business Enterprise Grant program to assist grantees in designing and constructing public works projects. A water reuse system serving a business or industrial park could potentially receive grant assistance through this program. An individual eligible business could apply for loan guarantees through the Rural Business-Cooperative Service to help finance a water reuse system that would support the creation of jobs in a rural area.

Other agencies that have funded projects in cooperation with USDA may provide assistance for water reuse projects if eligibility requirements are met include the Economic Development Administration, Housing and Urban Development (Community Development Block Grant), Appalachian Regional Commission, and the Delta Regional Commission.

Finally, the Bureau of Reclamation, authorized under Title XVI, the Reclamation Wastewater and Groundwater Study and Facilities Act; PL 102-575, as amended, Reclamation Recycling and Water Conservation Act of 1996; PL 104-266, Oregon Public Lands Transfer and Protection Act of 1998; PL 105-321, and the Hawaii

Water Resources Act of 2000; PL 106-566, provides for the Bureau to conduct appraisal and feasibility studies on water reclamation and reuse projects. The Bureau can then fund construction of reuse projects after Congressional approval of the appropriation. This funding source is restricted to activities in the 17 western states unless otherwise authorized by Congress. Federal participation is generally up to 25 percent of the capital cost.

Information about specific funding sources can be found in the *Catalog of Federal and Domestic Assistance,* prepared by the Federal Office of Management and Budget and available in federal depository libraries. It is the most comprehensive compilation of the types and sources of funding available.

6.2.2.4 State, Regional, and Local Grant and Loan Support

State support is generally available for wastewater treatment facilities, water reclamation facilities, conveyance facilities, and, under certain conditions, for on-site distribution systems. A prime source of state-supported funding is provided through SRF loans.

Although the number of states that have developed other financial assistance programs that could be used for reuse projects is still limited, there are a few examples. Texas has developed a financial assistance program that includes the Agriculture Water Conservation Grants and Loans Program, the Water Research Grant Program, and the Rural Water Assistance Fund Program. There is also a planning grant program – Regional Facility Planning Grant Program and Regional Water Planning Group Grants – that funds studies and planning activities to evaluate and determine the most feasible alternatives to meet regional water supply and wastewater facility needs.

Local or regional agencies, such as the regional water management districts in Florida, have taxing authority. In Florida, a portion of the taxes collected has been allocated to the funding of alternative water sources including reuse projects, which have been given a high priority, with as much as 50 percent of a project's transmission system eligible for grant funding. Various methods of prioritization exist, with emphasis on those projects that are of benefit to multi-jurisdictional users.

The State of Washington began its process of addressing water reclamation and reuse issues by passing the Reclaimed Water Act of 1992. In 1997, the State Legislature provided $10 million from the Centennial Clean Water Fund to help fund 5 demonstration projects. These projects have been completed and are currently providing reclaimed water for a variety of non-potable uses.

A comprehensive water reuse study in California concluded that funding was the primary constraint in implementing new water reuse projects (California State Water Resources Control Board, 1991).

To assist with the financial burden, grant funds are now available from the California Department of Water Resources for water conservation and groundwater management. Proposition 13 Safe Drinking Water, Clean Water, Watershed Protection and Flood Protection Bond Act provides funds for:

- Agriculture water conservation capital outlay
- Groundwater recharge construction loans
- Groundwater storage construction grants
- Infrastructure rehabilitation feasibility study grants
- Infrastructure rehabilitation construction grants
- Urban streams restoration program grants
- Urban water conservation capital outlay grants

AB303, the Local Groundwater Management Assistance Act of 2000, also provides grants. Funds have been used by Daly City, California to develop a groundwater-monitoring program and to refine models of the Westside Basin aquifer.

The passage of California's Proposition 50 in November 2002 makes funds available for projects to "protect urban communities from drought, increase supplies of clean drinking water, reduce dependence on imported water, reduce pollution of rivers, lakes, streams, and coastal waters, and provide habitat for fish and wildlife." This includes financing for "groundwater recharge and management projects." The State Water Resources Control Board (SWRCB) and the U.S. Bureau of Reclamation have played major roles in providing capital funding for local projects.

6.2.3 Capital Contributions

In certain circumstances, where reclaimed water is to be used for a specific purpose, such as cooling water, it may be possible to obtain the capital financing for new transmission facilities directly from one or more major users that benefit from the available reclaimed water supply.

One example of such a capital contribution would be construction of a major reuse transmission line by a developer who then transfers ownership to the utility for operation and maintenance. Another example is a residential housing developer, golf course, or industrial user who may provide the pipeline, financing for the pipeline, or provide for a pro-rata share of construction costs for a specific pipeline. In the event the private entity initially bears the entire capital cost of the improvement, such an approach may include provisions for reimbursement to the entity from future connections to the contributed facility for a specified period of time.

6.3 Internally Generated Funding Alternatives

While the preceding financing alternatives describe the means of generating construction capital, there is also a need to provide funding for OM&R costs, as well as debt service on borrowed funds. Examples of various internally-generated funding sources are highlighted, with details, in the following subsections.

In most cases, a combination of several funding sources will be used to recover capital and OM&R costs. The following alternatives may exist for funding water reuse programs.

- Reclaimed water user charges
- Operating budget and cash reserves of the utility
- Local property taxes and existing water and wastewater user charges
- Public utility tax
- Special assessments or special tax districts
- Connection fees

The City of Reno, Nevada, used a combination of special assessment districts bonds, revenue bonds, developer agreements, connection fee charges, user fees, and general fund advances as part of the creation of its reclaimed water system (Collins, 2000).

6.3.1 Reclaimed Water User Charges

The first source of funding considered should be a charge to those receiving reclaimed water services. As noted in the introduction, reclaimed water systems may well begin life as effluent disposal programs. Under such circumstances, reclaimed water "customers" are likely to be encouraged to use as much water as they want. A negligible fee may have been adopted to support the "all you can use" mentality. Very often a fixed rate will be used to simplify billing and eliminate penalties for overuse in the form of increased costs. While such an approach may seem to be justified when a project begins, this rationale for basing user fees falls by the wayside as water resources become stressed and reclaimed water supplies become a valuable resource. User charges would be utilized to generate a stream of revenues with which to defray the OM&R costs of the reuse facility and the debt service of any bonds or loans issued.

In a reclaimed water user charge system, the intent of an equitable rate policy is to allocate the cost of providing reuse services to the recipient. With a user charge system, it is implicit that there be select and identifiable user categories to which the costs of treatment and distribution can be allocated.

There are 2 prime means of allocating costs that are to be incorporated into a user charge: the proportionate share cost basis and the incremental cost basis. These 2 methods are discussed in more detail in Section 6.4.

Determining an equitable rate policy requires consideration of the different service needs of individual residential users (single-family and multi-family) as compared to other "larger" users with bigger irrigable areas, such as golf courses and green spaces. In many cases, a lower user rate can be justified for such large users than for residential customers. As an example, large users may receive reclaimed water into on-site storage facilities and then subsequently repump the water into the irrigation system, enabling the supplier to deliver the reclaimed water, independent of daily peak demands, using low-pressure pumps rather than providing high-pressure delivery on demand as required by residential users. Some multi-family customers may be treated as "large" users under this example, unless the reclaimed water is delivered at high pressure directly into the irrigation system. This flexibility in delivery and the low-pressure requirements can often justify the lower rate. At the same time, keeping reclaimed water rates competitive for large users when considering alternative sources of water, such as groundwater, is another consideration.

The degree of income from other sources, such as the general fund and other utility funds, must be considered in determining the balance of funding that must come from reuse rates. Residential user fees must be set to make water reuse an attractive option to potable water or groundwater. Alternatively, local regulations can prescribe that reclaimed water must be used for irrigation and other outdoor nonpotable uses in areas where it is available so usage becomes less sensitive to pricing. Although reclaimed water may have to be priced below potable water to encourage its use, reuse rates may also be set to discourage indiscriminate use by instituting volume (per gallon) charges rather than a flat fee; however, as reclaimed water has become recognized as an increasingly valuable element of an overall water resources plan, the trend is to meter reuse consumption to better monitor and control its use.

6.3.2 Operating Budget and Cash Reserves

Activities associated with the planning and possible preliminary design of reuse facilities could be funded out of an existing wastewater utility/department operating budget. A water supply agency seeking to expand its water resources would find it appropriate to apply a portion of its operating funds in a similar way. It could be appropriate, for example, to utilize funds from the operating budget for planning activities or business costs associated with assessing the reuse opportunity. Furthermore, if cash reserves are accruing for unspecified future capital projects, those funds could be used for design and construction costs, or a portion of the operating revenues from utility revenues can be set aside in a cash reserve for future needs.

The obvious advantage of using this alternative source of funding is that the utility board or governing body of the water and/or wastewater department or utility can act on its own initiative to allocate the necessary resources. These sources are especially practical when relatively limited expenditures are anticipated to implement or initiate the reuse program, or when the reuse project will provide a general benefit to the entire community (as represented by the present customers of the utility). In addition, utilizing such resources is practical when the reclaimed water will be distributed at little or no cost to the users, and therefore, will generate no future stream of revenues to repay the cost of the project. While it is ideal to fully recover all direct costs of each utility service from customers, it may not be practical during the early phases of a reuse system implementation.

6.3.3 Property Taxes and Existing User Charges

If the resources available in the operating budget or the cash reserves of the utility are not sufficient to cover the necessary system, OM&R activities, and capital financing debt, then another funding source to consider is revenues generated by increasing existing levies or charges. If some utility costs are currently funded with property taxes, levies could be increased and the new revenues designated for expenses associated with the reuse project. Similarly, the user charge currently paid for water and wastewater services could be increased. Like using the operating budget or cash reserves, the use of property taxes or user charges may be desirable if the expenditures for the project are not anticipated to be sizable or if a general benefit accrues to the entire community.

Ad valorem property taxes, unlike user charges, raise funds on the basis of assessed value of all taxable property, including residential, commercial, and industrial. Property value can be an appropriate means of allocating the costs of the service improvements if there is a “general good” to the community. It is also a useful means of allocating the cost of debt service for a project in which there is general good to the community and in which the specific OM&R costs are allocated to the direct beneficiaries. A contribution of *ad valorem* property tax revenues might be appropriate for such reuse applications as:

- Irrigation of municipal landscaping
- Fire protection
- Water for flushing sewers
- Groundwater recharge for saltwater intrusion barriers
- Parks and recreational facility irrigation

All such projects have benefits, either to the residents of the municipality in general, or to those who can be isolated in an identifiable special district.

Resources generated by increasing any existing user charges can be used in a similar manner. However, to do so equitably, benefits of the proposed project should primarily accrue to those presently utilizing the services of the water or wastewater utility. This would be the case, for example, when water reuse precludes the need to develop costly advanced treatment facilities or a new water supply source.

Contributions from the water and wastewater systems may be warranted whenever there is a reduction in the average day or peak day water demand or when the reuse system serves as a means of effluent disposal for the wastewater system. The City of St. Petersburg, Florida, for example, provides as much as 50 percent of the urban reuse system operations costs from water and wastewater system funds. The significant reduction in potable water demand achieved through water reuse has allowed the City to postpone expansion of its water treatment plant.

6.3.4 Public Utility Tax

The State of Washington took a rather innovative approach to funding when it passed a major water bill in 2001. The new law addresses several key areas in water resource management, including an incentive program to promote conservation and distribution of reclaimed water. The Public Utility Tax (Chapter 82.16 Revised Code of Washington) is levied on gross income of publicly and privately-owned utilities. The incentive program (Chapter 237), which exempts 75 percent of the amounts received for reclaimed water services for commercial and industrial uses, also allows reclaimed water utilities to deduct from gross income 75 percent of amounts expended to improve consumer water use efficiency or to otherwise reduce the use of water by the consumer. (Focus, Washington State Department of Ecology, August 2001) Examples of eligible measures are:

- Measures that encourage the use of reclaimed water in lieu of drinking water for landscape or crop irrigation

- Measures that encourage the use of moisture sensors, flow timers, low-volume sprinklers, or drip irrigation for efficiencies in reclaimed water use

Many variations on this incentive theme could be adopted by states, such as imposing a utility tax directly on large water users and granting exemptions for reclaimed water use.

6.3.5 Special Assessments or Special Tax Districts

When a reuse program is designed to be a self-supporting enterprise system, independent of both the existing water and wastewater utility systems, it may be appropriate to develop a special tax or assessment district to recover capital costs directly from the benefited properties. The advantage of this cost recovery mechanism is that it can be tailored to collect the costs appropriate to the benefits received. The City of Cape Coral, Florida, is one example of an area using special assessments to fund dual-water piping capital costs for fire protection and irrigation water. This special assessment was levied at an approximate cost of $1,600 per single-family residence with financing over 8 years at 8 percent annual interest. In addition, a monthly user charge is also applied to the water and wastewater billing to assist in defraying operating costs.

Special assessments may be based on lot front footage, lot square footage, or estimated gallon use relative to specific customer types. This revenue alternative is especially relevant if the existing debt for water and wastewater precludes the ability to support a reuse program, or if the area to be served is an independent service area with no jurisdictional control over the water or wastewater systems. The implementation of reclaimed water systems will reduce potable water consumption, corresponding to a reduction of revenues. This must be factored into the funding analysis.

6.3.6 Impact Fees

Impact fees, or capacity fees, are a means of collecting the costs of constructing an infrastructure element, such as water, wastewater, or reuse facilities, from those new customers benefiting from the service. Impact fees collected may be used to generate construction capital or to repay borrowed funds. Frequently, these fees are used to generate an equitable basis for cost recovery between customers connecting to the system in the early years of a program and those connecting in the later years. The carrying costs (interest expenses) are generally not fully recovered through the impact fee, although annual increases above a base cost do provide equity between groups connecting in the early years and those in later years.

Impact fees for water reuse systems are implemented at the discretion of the governing body. However, requiring a fee to be paid upon applying for service prior to construction can provide a strong indication of public willingness to participate in the reuse program. Incentive programs can be implemented in conjunction with impact fees by waiving the fee for those users who make an early commitment to connect to the reclaimed water system (e.g., for the first 90 days after construction completion) and collecting the fee from later connections.

6.4 Incremental Versus Proportionate Share Costs

6.4.1 Incremental Cost Basis

The incremental cost basis allocates only the marginal costs of providing service to the customer. This system can be used if the community feels that the marginal reclaimed water user is performing a social good by conserving potable water, and should be allocated only the additional increment of cost of the service. However, if the total cost savings realized by reuse are being enjoyed only by the marginal user, then in effect, the rest of the community is subsidizing the service. For example, an ocean outfall used as the primary means of effluent disposal could be tapped and reclaimed water mains extended to provide irrigation to one or more developments in an area that formerly used potable water. In this example, it may be appropriate to charge the developments only for the cost of installing the additional mains plus any additional treatment that might be required.

6.4.2 Proportionate Share Cost Basis

Under the commonly used proportionate share basis, the total costs of the facilities are shared by the parties in proportion to their usage. In apportioning the costs, consideration must be given to the quantity and quality of the water, the reserve capacity that must be maintained, and the use of any joint facilities, particularly means of conveyance. In determining the eventual cost of reuse to the customer base, the apportionment of costs among wastewater users, potable water users, and reclaimed water users must be examined. The allocation of costs among users also must consider the willingness of the local community to subsidize a reuse program.

A proportional allocation of costs can be reflected in the following equations:

Total wastewater service = wastewater treatment to permitted disposal standards + effluent disposal + transmission + collection

Total potable water service = water treatment + water supply + transmission + distribution

Total reclaimed water service = [reclaimed water treatment – treatment to permitted disposal standards] + additional transmission + additional distribution + additional storage

These equations illustrate an example of distributing the full costs of each service to the appropriate system and users. The first equation distributes only the cost of treating wastewater to currently required disposal standards, with any additional costs for higher levels of treatment, such as filtration, coagulation, or disinfection, assigned to the cost of reclaimed water service. In the event that the cost of wastewater treatment is lowered by the reuse alternative because current effluent disposal standards are more stringent than those required for the reuse system, the credit accrues to the total cost of reclaimed water service. This could occur, for example, if treatment for nutrient removal had been required for a surface water discharge but would not be necessary for agricultural reuse.

As previously noted, because reclaimed water is a different product from potable water and has restrictions on its use, it may be considered a separate, lower valued class of water and priced below potable water. Thus, it may be important that the user charges for reuse be below, or at least competitive with, those for potable water service. However, often the current costs of constructing reuse facilities cannot compete with the historical costs of an existing potable water system. One means of creating a more equitable basis for comparison is to associate new costs of potable water supplies to the current costs of potable water, as well as any more costly treatment methods or changes in water treatment requirements that may be required to meet current regulations. When creating reuse user fees, it may be desirable to deduct incremental potable water costs from those charged for reuse because reuse is allowing the deferral or elimination of developing new potable water supplies or treatment facilities. The perceived inequalities between reclaimed water and potable water may be eliminated where potable water is in short supply and subject to seasonal (or permanent) restrictions. For customers that cannot tolerate uncertainty in deliveries, a source of reclaimed water free from restrictions might be worth more than traditional supplies.

To promote certain objectives, local communities may want to alter the manner of cost distribution. For example, to encourage reuse for pollution abatement purposes by eliminating a surface water discharge, the capital costs of all wastewater treatment, reclaimed water transmission, and reclaimed water distribution can be allocated to the wastewater service costs. To promote water conservation, elements of the incremental costs of potable water may be subtracted from the reuse costs to encourage use of reclaimed water.

For water reuse systems, the proportionate share basis of allocation may be most appropriate. The allocation should not be especially difficult, because the facilities required to support the reuse system should be readily identifiable. As shown in the previous equations, it is appropriate to allocate to wastewater charges the costs of all treatment required for compliance with NPDES permits. All additional costs, including the costs of reclamation and conveyance of reclaimed water, would be allocated to the water reuse user charge.

General and administrative costs should also be allocated proportionately to all services just as they would be in a cost-of-service allocation plan for water and wastewater service. In some cases, lower wastewater treatment costs may result from initiating reclaimed water usage. Therefore, the result may be a reduction in the wastewater user charge. In this case, depending on local circumstances, the savings could be allocated to either the wastewater customer or the reclaimed water customer, or both.

Table 6-1 provides a range of credits that can be applied to the financial analysis of water reclamation projects based on experience in California (Sheikh *et al.,* 1998).

With more than one category or type of reclaimed water user, different qualities of reclaimed water may be needed. If so, the user charge becomes somewhat more complicated to calculate, but it is really no different than calculating the charges for treating different qualities of wastewater for discharge. If, for example, reclaimed water is distributed for 2 different irrigation needs with one requiring higher quality water than the other, then the user fee calculation can be based on the cost of treatment to reach the quality required. This assumes that it is cost-effective to provide separate delivery systems to customers requiring different water quality. Clearly this will not always be the case, and a cost/benefit analysis of treating the entire reclaimed water stream to the highest level required must be compared to the cost of separate transmission systems. Consideration should also be given to providing a lower level of treatment to a single reclaimed water transmission system with additional treatment provided at the point of use as required by the customer.

Estimating the operating cost of a reclaimed water system involves determining those treatment and distribution components that are directly attributable to the reclaimed water system. Direct operating costs involve additional treatment facilities, distribution, additional water quality monitoring, and inspection and monitoring staff. Any costs saved from effluent disposal may be considered a credit. Indirect costs include a percentage of administration, management, and overhead. Another cost is replacement reserve, i.e., the reserve fund to pay for system replacement in the future. In many instances, monies generated to meet debt service coverage requirements are deposited into replacement reserves.

6.5 Phasing and Participation Incentives

The financing program can be structured to construct the water reuse facilities in phases, with a target percentage of the potential customers committed to using reclaimed water prior to implementation of each phase. This commitment assures the municipal utility decision makers that the project is indeed desired and ensures the financial stability to begin implementation. Incentives, such as a reduction or waiver of the assessment or connection fee for those connections to the system within a set time frame, can be used to promote early connections or participation. The San Antonio, Texas, reclaimed water system charges for reclaimed water will be $280/acre-foot ($0.86/1,000 gallons), the same as the cost of potable water. As an incentive for users to sign up for this service, the city offered a one-time $900/acre-foot ($2.76/1,000 gallons) credit to cover the user's costs of converting to reclaimed water (Martinez, 2000).

Adequate participation to support implementation can be determined by conducting an initial survey in a service area, followed by a formal voted service agreement for each neighborhood. If the required percentage of residents in a given neighborhood agree to participate, facilities will be constructed in that area. Once this type of measure is taken, there is an underlying basis for either assessing pipeline costs, or charging using a monthly fixed fee, because the ability to serve exists. The rate policy may also include a provision for assessments or charges for undeveloped properties within a neighborhood served by a reclaimed water system.

Table 6-1. Credits to Reclaimed Water Costs

Benefit	Applicability	Value ($/acre-feet)
Water supply	Very common	$300 - $1,100
Water supply reliability	Very common	$100 - $140
Effluent disposal	Very common	$200 - $2,000
Downstream watershed	Common	$400 - $800
Energy conservation	Situational	0 to $240

6.6 Sample Rates and Fees

6.6.1 Connection Fees

Connection charges to a dual distribution system are often based on the size of the reclaimed water system being served. For example, in Cocoa Beach, Florida, customers are charged a connection fee based on the size of the reclaimed water service line. The connection fees are $100, $180, and $360 for a 3/4-inch, 1-inch, and 1-1/2-inch service line, respectively.

As an alternative to connection fees, a flat monthly rate can be charged to each user for a specified length of time until the capital costs associated with the system are paid off. This alternative is often preferred to spread out the costs associated with connection fees.

6.6.2 User Fees

The procedure for establishing rates for reclaimed water can be similar to the procedure for establishing potable water and wastewater rates. If reclaimed water is metered, then user rates can be based upon the amount of reclaimed water used. This will tend to temper excessive use. If meters are not used, then a flat rate can be charged. **Table 6-2** presents user fees for a number of existing urban reuse systems.

It is common for the cost of reclaimed water service to be based on a percentage of the cost of potable water service. One might assume that reclaimed water rates would always be less than that of potable water but this may not be the case. A recent survey of reclaimed water utilities in California (**Table 6-3**) shows the range of discounts for reclaimed water (Lindow and Newby, 1998). This survey clearly shows that reclaimed water can command rates equal to that of potable water depending on the specific nature of local water resources.

Table 6-3. Discounts for Reclaimed Water Use in California

Jurisdiction	Cost Percentage of Potable Water (%)
City of Long Beach	53
Marin Municipal Water District	56
City of Milpitas	80
Orange County Water District	80
San Jose Water Company	85
Irvine Ranch Water District	90
Carlsbad Municipal Water District	100
East Bay Municipal Utility District	100
Otay Water District	100

Figure 6-1 provides the results of a similar survey of potable and reclaimed water rates for utilities in southwest Florida (Personal Communication with Dennis Cafaro, 2003). With the exception of Barron Collier utilities, reclaimed water rates tend to be less than 50 percent of the potable water rates, with some rates for reuse less than 20 percent that of potable water. These results provide additional evidence that reclaimed water rates are highly dependent on local conditions.

To further reinforce the concept that reclaimed water is a valuable resource, utilities may consider not only charging for reclaimed water by the gallon, but also implementing a conservation rate structure to encourage efficient use. Conservation rate structures provide economic incentives for consumers to limit water use. To the extent possible, they should achieve similar results in all customer classes, be equitable within and among customer classes, support the utility's financial requirements, and can be revenue neutral. Structures can significantly reduce water use without government expenditure or new regulation, while helping to protect both the quantity and quality of water resources. For example, at system start-up some residential customers in the City of Venice, Florida were charged a flat rate for reclaimed water service. When the rate structure was changed to charge customers for the actual volume of water used, including an inclining conservation rate, demand was reduced by 10 to 15 percent. However, no change in the peak demand water use was observed – suggesting peak use was driven by actual need and reductions were the result of more efficient water use in low demand periods (Farabee *et al.,* 2002).

6.7 Case Studies

6.7.1 Unique Funding Aspects of the Town of Longboat Key, Florida Reclaimed Water System

Longboat Key is a barrier island community located on Florida's Gulf coast. The town lies within 2 counties—the northern portion of Longboat Key is in Manatee County and the southern portion is in Sarasota County. The island is surrounded by the Gulf of Mexico on the west and Sarasota Bay on the east. The town's geographical location severely limits local water resources. Since its inception in 1972, the Town of Longboat Key has received potable water and wastewater services from Manatee County.

Landscape irrigation accounts for approximately a quarter of the town's potable water use. In 2002, it was necessary for the town to seek an alternative water source for irrigation since its current potable water use exceeded what is available through Manatee County agreement al-

Table 6-2. User Fees for Existing Urban Reuse Systems

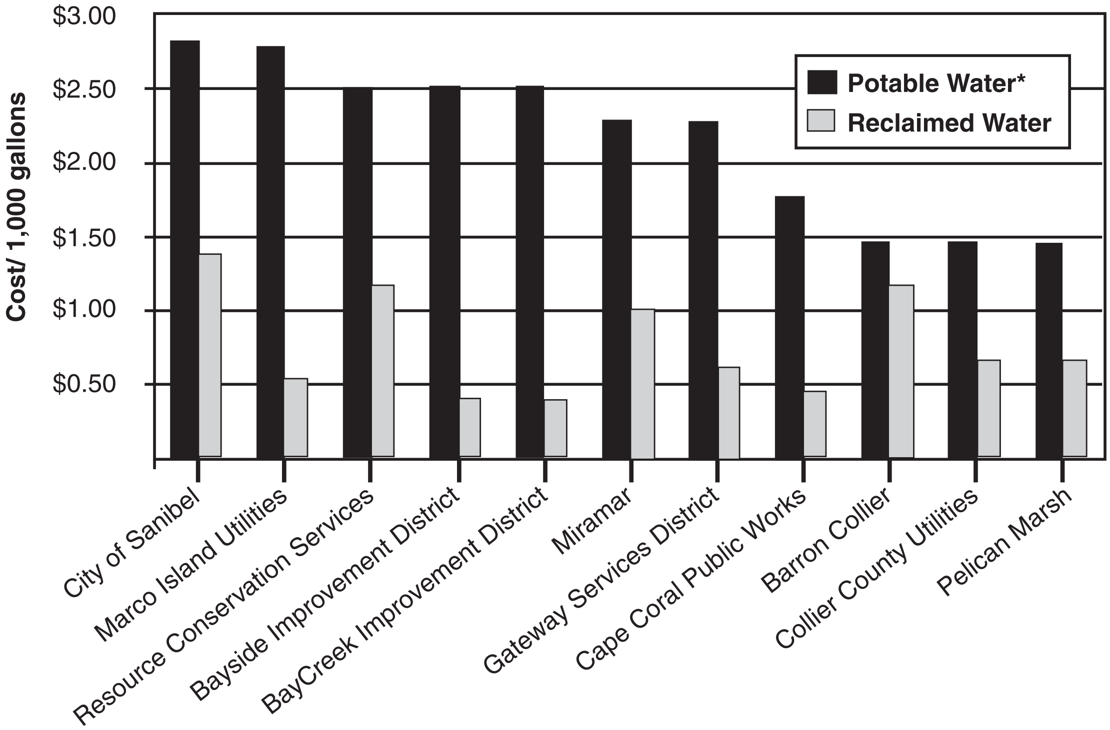
Location	User Fee
Amarillo, Texas[1]	$0.15/1,000 gallons
Cocoa Beach, Florida[1]	Residential (not metered): ▪ $8/month/acre Commercial (metered): ▪ $0.26/1,000 gallons
Colorado Springs, Colorado[1]	$0.00685/cubic foot ($0.91/1,000 gallons)
County of Maui, Hawaii[1]	Major agriculture: ▪ $0.10/1,000 gallons Agriculture, golf course: ▪ $0.20/1,00 gallons Other: ▪ $0.55/1,000 gallons
Henderson, Nevada[1]	$0.71/1,000 gallons
San Rafael, California[1]	Tier 1: $2.02/CCF for 0-100% of water budget Tier 2: $3.89/CCF for 100-150% of water budget Tier 3: $7.64/CCF for over 150% of water budget
South Bay, California[1]	Inside service area: ▪ $280/AF ($0.86/1,000 gallons) for 0-25 AF/month ▪ $260/AF ($0.80/1,000 gallons) for 25-50 AF/month ▪ $240/AF ($0.74/1,000 gallons) for 50-100 AF/month ▪ $220/AF ($0.68/1,000 gallons) for 100-200 AF/month ▪ $200/AF ($0.61/1,000 gallons) for 200+ AF/month
St. Petersburg, Florida[1]	Residential (not metered): ▪ $10.36/month for first acre + $5.92/month for each additional acre
Wheaton, Illinois[1]	$0.18/1,000 gallons
Summary of Florida Reuse Systems[2]	Residential - Flat Rate ($/month) ▪ Average = $13.81 ▪ Range = $0.00 - $350.00[3] Residential - Gallonage Charge ($/1,000 gallons) ▪ Average = $0.32 ▪ Range = $0.00 - $1.25 Non-Residential - Flat Rate ($/month) ▪ Average = $445.35 ▪ Range = $0.00 - $12,595.00 Non-Residential Gallonage Charge ($/1,000 gallons) ▪ Average = $0.26 ▪ Range = $0.00 - $2.50

[1] User fees as reported in management practices for nonpotable water reuse, Project 97-IRM-6, Water Environment Research Foundation, 2001.

[2] Reuse Rates as reported in the Florida Department of Environmental Protection, Reuse Inventory Report, June 2002.

[3] Includes lump sum rates charged to residential developments as well as individual residential customers.

Figure 6-1. Comparison of Reclaimed Water and Potable Water Rates in Southwest Florida



*Base rate cost of potable water
(Many utilities use an inclining rate structure for potable water.)

locations. Historically, the town has also used groundwater to meet approximately 80 percent of its irrigation demands. However, a decline in groundwater quality attributed to saltwater intrusion caused by long-term withdrawals and probable overpumping has been observed.

After the review and evaluation of many alternatives, the Town of Longboat Key opted for a reclaimed water system with supply provided by an adjoining jurisdiction, the City of Sarasota, Florida. The project will require:

- Installation of a subaqueous reclaimed water transmission main across Sarasota Bay
- Construction of aquifer storage and recovery facilities
- Construction of delivery pumping stations
- Construction of a 2.5-million-gallon (9,460-m^3) storage tank
- Construction of associated distribution mains

The Longboat Key reclaimed water transmission system will connect to the City of Sarasota's existing reclaimed water system. Two and a half million gallons per day of reclaimed water will be available from the City of Sarasota. The conceptual planning cost for the project is estimated to be $28,166,000.

The reclaimed water rate structure has been designed so the system can be financially self-sufficient. The end user costs are the true cost of providing the service. The estimated cost per 1,000 gallons will be approximately $2.67. By obtaining funding through the SRF loan program, the town will be able to satisfy the capital requirements for system implementation. Since loan repayments are not required to begin until 1 year after completion of the facility, semi-annual debt service payments and OM&R costs will be satisfied from the operating revenues of the reclaimed water system.

Water and wastewater revenues are not intended to be used to pay for the reclaimed water system, but instead will serve as a backup pledge to the pledge of reclaimed water revenues for the SRF loan. To the extent that water and wastewater revenues are used to make any semi-annual loan payments, the town intends to reimburse its water and wastewater revenues fund with reclaimed water revenues.

The reclaimed water revenue source is contingent on commitments in the form of user agreements from condominium and homeowner's associations. The public has voted for a town-required referendum authorizing the financing of a reclaimed water system.

6.7.2 Financial Assistance in San Diego County, California

Water reclamation is an important component of the San Diego region's local water resources. A number of agencies in San Diego continue to implement and expand their water reuse projects. Currently, about 12,000 acre-feet (3.9 billion gallons) per year of reclaimed water is beneficially reused within the service area of Water Authoriy Board of the County of San Diego (Authority). Approximately 64 percent of the water is used for agriculture, landscape irrigation, and other municipal and industrial uses; the remaining 36 percent is recharged into groundwater basins. This number is projected to increase to over 53,000 acre-feet per year (17.3 billion gallons per year) by 2020.

Financial assistance programs play a critical role in the development of reclaimed water supplies. There are a number of financial assistance programs available to San Diego County agencies: the Authority's Financial Assistance Program (FAP) and Reclaimed Water Development Fund (RWDF); the Metropolitan Water District of Southern California's Local Resources Program (LRP); the U.S. Bureau of Reclamation's Title XVI Grant Program; and the State Water Resources Control Board's low-interest loan programs. Together, these programs offer funding assistance for all project phases, from initial planning and design to construction and operation. Examples of how these funds facilitate water reuse projects in San Diego are described below:

- FAP provides loans to Authority member agencies for water reuse facilities planning, feasibility investigations, preliminary engineering studies, and research projects related to water reuse and/or groundwater development. The Authority provides funding on a 50:50 cost sharing basis up to $50,000 for any given project activity.

- FAP funds are also available for research and development in the form of grants. In order to receive FAP funding for these types of studies, a local agency must have secured partial funding from at least one other source such as the American Water Works Association Research Foundation (AWWARF), Desalination Research and Innovation Partnership (DRIP), Water Environmental Research Foundation (WERF), Proposition 13, etc.

- RWDF provides Authority member agencies financial assistance up to $100 per acre-foot ($0.31 per 1,000 gallons) for the development of reclaimed water projects capable of relieving a demand on the Authority. Project expenses must exceed project revenues. Funding is available for up to 25 years based on financial need.

- LRP is designed to ensure the financial feasibility of local projects during the initial years of operation. The Metropolitan Water District of Southern California offers an incentive of up to $250 per acre-foot ($0.77 per 1,000 gallons) for up to 25 years for reclaimed water and groundwater development projects that offset demands for imported water.

6.7.3 Grant Funding Through the Southwest Florida Water Management District

The Southwest Florida Water Management District (SWFWMD) is 1 of 5 water management districts in Florida with responsibilities for: water quality, natural systems improvement, flood protection, and water supply in a 10,000-square-mile (25,900-km^2) area. The SWFWMD is unique among the water management districts in Florida in that, beyond the similar structure of the governing boards, it has 9 basins with jurisdictional boundaries encompassing the major watersheds making up the District. In 8 of the 9 basins, populations have increased such that boards have been appointed to react to local, sub-regional water resource issues. These boards sponsor projects in coordination with local governments, private citizens, and private businesses, to improve, protect, and restore the water resources of their respective areas. These basin boards, like the Governing Board, have the authority to levy *ad valorem* taxes up to 0.5 of a mil within their boundaries.

The SWFWMD basin boards have provided local funds for local water resource-related projects since the District's creation in 1961. Originally, the focus of the basin boards and the Governing Board was on funding flood control projects. In the late 1980s, the basin priorities began to shift to the identification and funding of projects that focus on water conservation and the development of alternative water sources.

Recognizing the importance of their ability to support local governments by providing solutions to the growing issues surrounding water supply, the basins adopted a more proactive role in addressing local non-regulatory water issues. The Cooperative Funding Initiative, New Water Sources Initiative, and Water Supply and Resource Development funding was established in recognition of the growing need for a structured approach to projects in order to maximize the SWFWMD's effectiveness in choosing and funding water resource projects and budgeting for their completion.

The SWFWMD funds up to 50 percent of a project's capital cost and over the past 15 years has budgeted more than $182,000,000 in financial contributions towards reclaimed water development. As a result of Governing Board and basin board participation, more than 214 reuse projects totaling $494,000,000 in capital costs have been funded since Fiscal Year 1987.

Source: SWFWMD, 2003.

6.7.4 Use of Reclaimed Water to Augment Potable Supplies: An Economic Perspective (California)

To accurately assess the cost-effectiveness of any reuse project, including an indirect potable water reuse project, all potential benefits of the project must be considered. The beneficial effects of an indirect potable reuse project often extend beyond the sponsoring agency, providing regional benefits and, in many cases, benefits that extend statewide and beyond. In certain settings, indirect potable reuse projects may provide for large-scale beneficial use of reclaimed water with relatively modest additional infrastructure requirements. Examples of 2 such indirect potable reuse projects are underway in California: the East Valley Water Recycling Project (EVWRP), and the Orange County Groundwater Replenishment (GWR) System.

East Valley Water Recycling Project

Phase IA of the EVWRP includes approximately 10 miles (16 km) of 54-inch (137-cm) diameter pipeline and a pumping station to deliver tertiary treated reclaimed water from the Donald C. Tillman Water Reclamation Plant to the Hansen Spreading Grounds. Phase IA also includes an extensive monitoring well network designed to track the reclaimed water as it travels through the San Fernando Groundwater Basin from the spreading grounds to domestic production wells. This project will initially deliver up to 10,000 acre-feet per year (6,200 gpm) to the Hansen Spreading Grounds. Phase IB of the EVWRP will include construction of an additional pipeline to deliver reclaimed water to the Pacoima Spreading Grounds.

The cost of Phase IA is estimated at approximately $52 million. Up to 25 percent of this cost is being funded by the federal government through the Federal Reclamation Projects Authorization and Adjustment Act of 1992. Up to 50 percent of the total cost is being funded by the State of California through the Environmental Water Act of 1989. The remaining 25 percent of the total cost is being funded by ratepayers through special conservation and reclamation rate adjustments. **Table 6-4** provides calculations, in cost per acre-foot, for reclaimed water with and without federal and state requirements.

Based on these funding reimbursement percentages, Phase IA of the EVWRP will provide water at an estimated cost of $478 per acre-foot ($1.47 per 1,000 gallons), with a net cost of approximately $194 per acre-foot ($0.60 per 1,000 gallons) when state and federal funding is considered. Even if state or federal funding had not been available, the EVWRP would still provide a new reliable source of water at a cost comparable to other water supplies, and significantly less expensive than other new supply options. (According to the City Of Los Angeles Department of Water and Power Urban Water Management Plan Fiscal Year 1997-1998 Annual Update, seawater might be desalinated using new technology, which has produced desalted ocean water at a cost of about $800 per acre-foot ($2.35 per 1,000 gallons) in pilot tests, or approximately $2,000 per acre-foot ($6.14 per 1,000 gallons) using current technology.) Furthermore, the EVWRP has other benefits, which have not been quantified, such as the reduction of water imported from the Mono Basin and improved water system reliability resulting from a new local supply of water.

Orange County Groundwater Replenishment (GWR) System

Under the Orange County GWR System, highly treated reclaimed water will be pumped to either existing spreading basins, where it will percolate into and replenish the groundwater supply, or to a series of injection wells that act as a seawater intrusion control barrier. The GWR System will be implemented in 3 phases, providing a peak daily production capacity of 78,400 acre-feet per year (70 mgd) by the year 2007, 112,000 acre-feet per year (100 mgd) by 2013, and 145,600 acre-feet per year (130 mgd) by 2020.

Table 6-5 shows a conservative preliminary estimate of the capital and OM&R costs for Phase I of the GWR System based on December 2003 estimates.

The expected project benefits and their economic values (avoided costs) include:

Table 6-4. Estimated Capital and Maintenance Costs for Phase IVA With and Without Federal and State Reimbursements

	Without Federal and State Reimbursement	With 25% Federal and 50% State Reimbursement
Capital Costs	$52,000,000	$52,000,000
State Reimbursement (50%)	-0-	$26,000,000
Federal Reimbursement (25%)	-0-	$13,000,000
Net DWP Capital Expenditure	$52,000,000	$13,000,000
Amortized Net Capital Expenditure (6% interest for 30 years)	$3,777,743	$944,436
Operation & Maintenance Cost per Acre-foot (AF)	$100	$100
Annual Delivery	10,000 AF	10,000 AF
Cost of Delivered Water	$478 per acre-foot ($1.47 per 1,000 gal)	$194 per acre-foot ($0.60 per 1,000 gal)

1. Alternative Water Supply – If the GWR System is not implemented, Water Factory 21 would have to be rehabilitated at a construction cost of approximately $100 million to provide the water needed for seawater intrusion control via groundwater injection. Additional imported water at a yearly cost of approximately $4 million to $10 million would have to be purchased for use at the spreading basins as recharge water. In times of drought, there is also a penalty imposed on using imported water supplies, ranging from $175 to $250 per acre-foot, potentially adding fees up to $10.7 million a year. By implementing the GWR System, approximately $27.4 million in annual costs are avoided.

2. Salinity Management – The OCWD uses water from the Santa Ana River (consisting of upstream treated wastewater discharges and stormwater) and imported water (from the Colorado River Aqueduct and the State Water Project) to percolate into the forebay area of the Orange County groundwater basin. The treated wastewater discharges and water from the Colorado River are high in TDS, with concentrations over 700 mg/l. Higher TDS water can cause corrosion of plumbing fixtures and water heaters. Normalized costs for more frequent replacement of plumbing and water using fixtures and appliances are estimated to range from $100 to $150 per household each year. Over time, the reverse osmosis-treated product from the GWR System will lower the overall TDS content of the groundwater basin, saving the average household approximately $12.50 per year (or $25/acre-foot, $0.08 per 1,000 gallons). Industries and other large water users might also realize significant savings. From the standpoint of salinity management, the GWR System provides an annual benefit of $16.9 million.

3. Delay/Avoid Ocean Outfall Construction – Implementation of the GWR System will divert up to 100 mgd

Table 6-5. Cost Estimate for Phase I of the GWR System

Item	Cost
Capital Costs	$453.9 Million
Operation & Maintenance	$26.7 Million/year
Grant Receipts	$89.8 Million
Interest	2.6% amortized over 25 years
Power Cost	$0.11per kwh
Capacity Utilization	50% Barrier injection 50% Recharge percolation

(4,380 l/s) of peak wastewater flow during Phase I from the Sanitation District's ocean outfall disposal system. The estimated $175 million cost of a new ocean outfall can be delayed at least 10 years by applying several peak reduction methods, including diverting water to the GWR system instead of discharging to the ocean outfall.

Economic Summary

The annual cost to implement the GWR System – including capital, OM&R, engineering, administration, and contingencies, at 2.6 percent interest and amortized over a 25-year period – would be approximately $37.1 million. Totaling the avoided costs, the total annual benefits are as shown in **Table 6-6**.

This results in a maximum benefit-to-cost ratio of 1.33 ($49.2/$37.1). Based on this analysis, Orange County Water District and Orange County Sanitation District have decided to move forward with the implementation of this project.

The EVWRP and the GWR System exemplify how indirect potable reuse projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. The ultimate success of these projects would be attributable to project sponsors reaching out and forming alliances with the full array of beneficiaries.

The EVWRP and the GWR System exemplify how indirect potable reuse projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. The ultimate success of these projects would be attributable to project sponsors reaching out and forming alliances with the full array of beneficiaries.

Source: WateReuse Association, 1999. Updated by CDM/OCWD Project Team, 2004.

6.7.5 Impact Fee Development Considerations for Reclaimed Water Projects: Hillsborough County, Florida

Hillsborough County is located on the central-west coast of the State of Florida. The unincorporated area encompasses 931 square miles (2,411 km^2), or more than 86 percent of the total county area. Approximately 650,000 residents live in unincorporated Hillsborough County, and most of them are served by various community services provided by the County. The Hillsborough County Water Department is responsible for providing treatment and delivery of potable water, wastewater collection, and treatment and distribution of reclaimed water within unincorporated Hillsborough County. The Department currently saves about 10 mgd (440 l/s) of potable water through reuse. Future expansion of the reclaimed water system is expected to save about 30 mgd (1,315 l/s) of potable water by the year 2020.

Florida continues to be a rapidly growing state. To address the need for additional infrastructure, local governments have turned to development impact fees. Development impact fees are charges applied to new development to pay for the construction of new facilities or for the expansion of existing ones to meet these demands. Water and wastewater utilities are no exception. At least half of Florida's 67 counties use some form of impact fees to pay for expansion of their water and wastewater utility that is necessitated by growth in the community.

The following 3 criteria must be met to justify these fees: (1) there must be a reasonable connection between growth from new development and the resultant need for the

Table 6-6. Total Annual Benefits

Item	Total Annual Cost Avoidance (Millions $)
Orange County Water District (OWCD) Cost Avoidance	$27.40
Salinity Management	$16.90
Orange County Sanitation District (OCSD), Delay in outfall	$4.90
Total Benefits	$49.20

new service; (2) the fees charged cannot exceed a proportionate share of the cost incurred in accommodating the new users paying the fee; and (3) there must be a reasonable connection between the expenditure of the fees that are collected and the benefits received by the new customers paying the fees.

Several years ago, Hillsborough County decided to fund a portion of the cost of new reclaimed water projects through the capacity fee mechanism. It was recognized that the service benefits reclaimed water customers as well as new customers to the system that do not necessarily receive the reclaimed service. Specifically, reclaimed water projects have the unique characteristic of providing capacity in both the water and wastewater components of a traditional utility.

The Department's potable water investment since 1986, when the majority of the debt for the existing system was issued, is approximately $175 million with a corresponding potable water capacity of 54.5 mgd (2,400 l/s). The level of service prior to potable water conservation benefits derived from using reclaimed water was approximately 350 gpd (1,325 l/d) per Equivalent Residential Connection (ERC). Based on this level of service, the 54.5 mgd (2,400 l/s) potable water capacity would serve 155,714 ERCs. However, since reclaimed water service has been implemented, the Department has been able to reduce the level of service to 300 gpd (1,135 l/d) per ERC. The same 54.5 mgd (2,400 l/s) of capacity is now able to serve 181,667 ERCs with no additional investment in potable water capacity. This equates to 25,953 additional ERCs being served due to reclaimed water use – or a potable water capacity avoidance at the 350-gpd (1,325 l/d) level of service of 9.1 mgd (400 l/s). Assuming a cost of $5.25 per gpd for additional potable water capacity based on desalination treatment, the potable water capacity cost avoided is approximately $47.78 million.

The Department has 8 wastewater treatment plants with a total permitted treatment capacity of 48.5 mgd (2,125 l/s). These treatment plants have permitted effluent disposal capacity in the form of a surface-water discharge for 24 mgd (1,050 l/s). The difference of 24.5 mgd (1,075 l/s) is the effluent disposal benefit obtained from reclaimed water. Using a cost of $2.40 per gpd for either land application or deep-well injection methods for alternate effluent disposal, this results in an effluent disposal cost avoided of approximately $58.8 million.

Using these calculations, the total cost avoided for both water and wastewater is $106.58 million. The potable water capacity cost avoided and the effluent disposal cost avoided were each divided by this total cost to determine the allocation of reclaimed water project costs associated with water and wastewater. This resulted in a reclaimed water project cost split of 45 percent to water and 55 percent to wastewater.

The current North service area capacity fee is $1,335 for water and $1,815 for wastewater. For the South/Central service area, the current capacity fee is $1,440 for water and $1,970 for wastewater. **Table 6-7** provides the percentage of the capacity fees that have been attributed to reclaimed water projects in these service areas.

6.7.6 How Much Does it Cost and Who Pays: A Look at Florida's Reclaimed Water Rates

Reclaimed water is becoming an increasingly valuable water resource in Florida in terms of groundwater recharge, conservation of potable quality water, and drinking water cost savings to the consumer (since reclaimed water is usually less expensive than drinking water to the consumer). In fact, reuse has become so popular that some utilities have had trouble keeping up with the demand.

In order to meet the high demand for reclaimed water, some utilities have used other sources (i.e., groundwater, surface water, etc.) to augment their reclaimed water supply. Others deal with high reclaimed water demand by imposing watering restrictions on reuse customers, and/or limiting or prohibiting new customer connections to the reuse system. Many reclaimed water suppliers used these methods to try to meet demands when the

Table 6-7. Reclaimed Water Impact Fees

Service Area	Percent of Water Capacity Fee Allocated to Reclaimed Water	Percent of Wastewater Fee Allocated to Reclaimed Water
North	8	29
South/Central	6	18

state was faced with a drought, but a few suppliers still struggled. The need to conserve and properly manage reclaimed water as a valuable resource became very clear.

In the past, many utilities provided reclaimed water at no cost to the customer or based on a fixed monthly charge, regardless of use. Since the water was free or sold at low flat rates, customers used as much as they wanted, which was usually more than they needed. Now, many utilities are moving towards volume-based charges for reclaimed water service. Although the main intent of charging reuse customers for reclaimed water is to recover the costs associated with reuse facilities, reuse customers that are charged by the gallon for reclaimed water service tend to be more conservative in their use of the water supply.

1999 Florida Reclaimed Water Rates

Every year, the Florida Department of Environmental Protection publishes the *Reuse Inventory* that contains a good deal of useful information regarding water reclamation facilities in Florida, including reuse rates charged by facilities. The *1999 Reuse Inventory* (FDEP, 2000) compiles rates under 2 categories, Residential and Non-Residential. A survey based on information from the *1999 Reuse Inventory* for 176 reuse systems revealed the following:

Non-Residential Category: Forty-five percent of the reuse systems provided reclaimed water free of charge, 33 percent charged by the gallon, about 10 percent charged a flat rate, and 12 percent incorporated the base facility charge and the gallonage charge.

Residential Category: Eight percent of the systems surveyed provided reclaimed water free of charge, 12 percent by the gallon, 22 percent charged a flat rate, and about 10 percent utilized the base facility charge and the gallonage charge. (48 percent of the systems surveyed did not provide residential service.) The average rates associated with each rate type are shown in **Table 6-8**.

According to an AWWA survey, reuse rates are developed in many different ways. Out of 99 facilities surveyed, 19 percent set the rate at a percentage of the potable water rate, 14 percent base the rate on the estimated cost of the reuse service, 24 percent set the rate to promote use, 9 percent base the rate on market analysis, and 33 percent use other methods to develop reuse rates. The survey also revealed what percentages of costs were recovered through reuse rates for these facilities as shown in **Table 6-9**.

Fifty-three percent of 97 facilities surveyed charge a uniform rate for reclaimed water, approximately 6 percent charge inclining block rates, 2 percent charge declining block rates, and 6 percent charge seasonal rates. The other 33 percent used some other type of rate structure (AWWA, 2000). The survey shows that the majority of reuse customers are metered. The average metered rate of 16 surveyed facilities was $1.12/1,000 gallons.

In order to determine the relationship between how much reclaimed water a reuse customer used and how much they were charged for the service, the Southwest Florida Water Management District (SWFWMD) conducted a survey of utilities in Pinellas County that provided reclaimed water to residential customers. This survey revealed that residential customers who were charged a flat rate used an average of 1,112 gallons of reclaimed water per day, while residential customers who were charged per 1,000 gallons only used an average of 579 gallons per day (Andrade, 2000). The average metered rate charged by these utilities was $0.61/1000 gallons. The average flat rate charged by these utilities was $9.77/month. Based on the average usage of 1,112 gallons per day reported for residential customers, this flat rate translates to a metered rate of $0.29/1000 gallons.

Source: Coleman and Andrade, 2001

Table 6-8. Average Rates for Reclaimed Water Service in Florida

	Non-Residential	Residential
Flat Rate 1*	$19.39/month	$6.85/month
Flat Rate 2**	$892,89/month	Not Applicable
Metered Rate	$0.26/1,000 gallons	$0.39/1,000 gallons
Flat Rate with Metered Rate	$29.99/month+$0.39/1,000 gallons	$7.05/month+$0.34/1,000 gallons

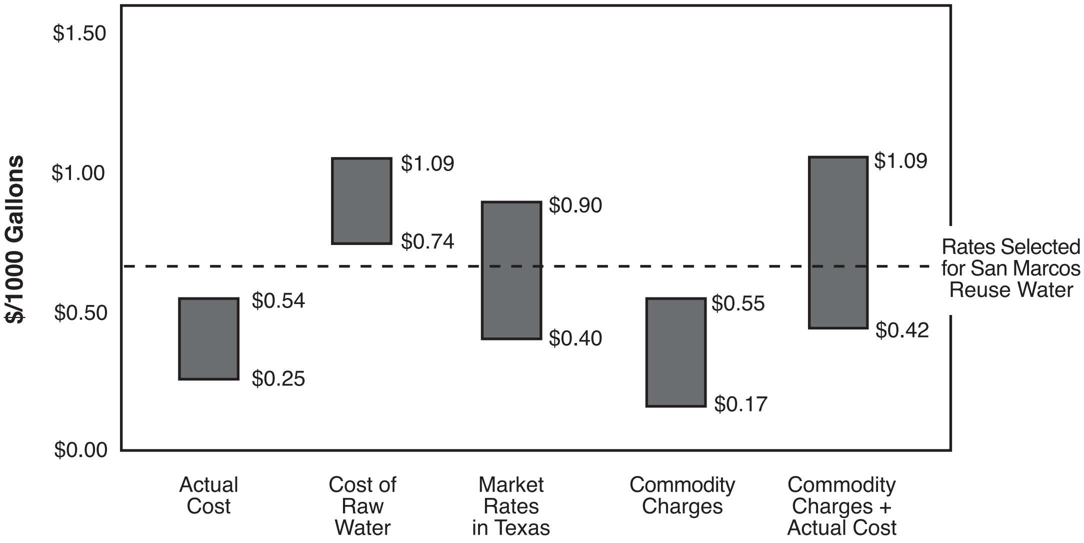
Table 6-9. **Percent Costs Recovered Through Reuse Rates**

Percent of Costs Recovered	Percent of Utilities Recovering Costs
Under 25 Percent	32
25 to 50 Percent	5
51 to 75 Percent	5
76 to 99 Percent	14
100 Percent	13
Unknown	31

6.7.7 Rate Setting for Industrial Reuse in San Marcos, Texas

The newly expanded San Marcos 9-mgd (395-l/s) advanced tertiary wastewater treatment plant is a state-of-the-art facility that produces some of the highest quality effluent in the State of Texas. The permit requirements are the toughest the Texas Natural Resources Conservation Commission deploys: 5/5/2/1/6 (BOD_5/TSS/NH_3/PO_4/DO). Since coming on-line last year, the quality of the effluent has consistently been better than the permit limits require. In this region of the state, the use of groundwater is discouraged and surface water is becoming less available and more costly; therefore, reclaimed water is becoming a marketable commodity. In January 1999, American National Power approached the City of San Marcos, as well as other cities in the Central Texas area between Austin and San Antonio, with a list of resources required for the power co-generation facility they were to build – *The Hays Energy Project (HEP)* – in anticipation of the imminent electrical power deregulation in Texas. Principal on the list was a reliable, economical source of both potable and process water, and a means of disposing of their domestic wastewater and process wastewater. The City had no existing wastewater treatment plant effluent customers and no historical basis for setting a rate to charge the HEP for delivering to them basically the City's entire effluent flow.

Figure 6-2. **Comparison of Rate Basis for San Marcos Reuse Water**



In considering rates to this industrial customer, the City of San Marcos investigated both the actual cost of producing and delivering reclaimed water as well as the market value of reclaimed water. By including only those facilities over and above what was required for normal wastewater treatment and disposal, the actual cost of delivering reclaimed water was determined to be between $0.25 to $0.54/1,000 gallons. A review of the existing costs of alternate suppliers of water in the region was then conducted to define the market value of reclaimed water to the industrial customers. This investigation included reuse rates charged elsewhere in the state and determined that the cost of alternate water supplies might range from $0.40 to $0.90/1,000 gallons. The results of this investigation are summarized in **Figure 6-2**.

Based on the results of this investigation, the City was able to consider reclaimed water as a commodity and set the charges as a function of available supplies, the demand for water and the benefits of the service. Through this process, the City established a charge of $0.69/1,000 gallon as shown in Figure 6-2.

Source: Longoria *et al.,* 2000.

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CHAPTER 7

Public Involvement Programs

In the years since this manual was first developed, the world has seen ever-increasing demands for water, often from competing interests, and often in the face of declining water supplies. As a result, water quality and quantity have become important public topics in many arenas, and regulatory agencies often require some level of stakeholder involvement in water management decisions. This is strikingly different from the past when members of the public were often informed about projects only after final decisions had been made. Today, responsible leaders recognize the need to incorporate public values with science, technology, and legal aspects to create real, workable solutions tailored to meet specific needs.

In the area of water reuse, the opportunities for meaningful public involvement are many. This chapter provides an overview of the key elements of public planning, as well as several case studies illustrating public involvement and/or participation approaches.

7.1 Why Public Participation?

Public involvement or participation programs work to identify key audiences and specific community issues at a very early stage, offering information and opportunities for input in a clear, understandable way. Effective public involvement begins at the earliest planning stage and lasts through implementation and beyond.

Public participation begins with having a clear understanding of the water reuse options available to the community. Once an understanding of possible alternatives is developed, a list of stakeholders, including possible users, can be identified and early public contacts may begin. Why begin contacting stakeholders before a plan is in place? These citizen stakeholders can provide early indications regarding which reuse program will be best accepted on a community-wide level. Beyond that, informed citizens can help identify and resolve potential problems before they occur and develop alternatives that may work more effectively for the community.

In general, effective public participation programs invite two-way communication, provide education, and ask for meaningful input as the reuse program is developed and refined. Depending on the project, public involvement can involve limited contact with a number of specific users, or can be expanded to include the formation of a formal advisory committee or task force. Often, public information efforts begin by targeting the most impacted stakeholders. Over time, as an early education base is built among stakeholders, the education effort then broadens to include the public at large. Regardless of the audience, all public involvement efforts are geared to help ensure that adoption of a selected water reuse program will fulfill real user needs and generally recognized community goals including public health, safety, and program cost.

The term, “two-way communications flow” cannot be too highly emphasized. In addition to building community support for a reuse program, public participation can also provide valuable community-specific information to the reuse planners. Citizens have legitimate concerns, quite often reflecting their knowledge of detailed technical information. In reuse planning, especially, where one sector of “the public” comprises potential users of reclaimed water, this point is critical. Potential users *generally* know what flow and quality of reclaimed water are acceptable for their applications.

7.1.1 Informed Constituency

By taking time during the planning stages to meet with citizens, communities will have a much greater opportunity to develop a successful reuse program. Many citizens may have a pre-conceived notion about reclaimed water and its benefits. It is important to identify each stakeholder’s issues and to address questions and concerns in a clear, matter-of-fact way. This two-way dialogue will lead to informed input regarding reuse alternatives.

A public participation program can build, over time, an informed constituency that is comfortable with the concept of reuse, knowledgeable about the issues involved in reclamation/reuse, and supportive of program implementation. Ideally, citizens who have taken part in the planning process will be effective proponents of the selected plans. Having educated themselves on the issues involved in adopting reclamation and reuse, they will also understand how various interests have been accommodated in the final plan. Their understanding of the decision-making process will, in turn, be communicated to larger interest groups – neighborhood residents, clubs, and municipal agencies – of which they are a part. Indeed the potential reuse customer who is enthusiastic about the prospect of receiving service may become one of the most effective means of generating support for a program. This is certainly true with the urban reuse programs in St. Petersburg and Venice, Florida. In these communities, construction of distribution lines is contingent on the voluntary participation of a percentage of customers within a given area.

In other communities where reuse has not been introduced in any form, the focus may begin with very small, specific audiences. For instance, a community may work closely with golf course owners and superintendents to introduce reuse water as a resource to keep the golf course in prime condition, even at times when other water supplies are low. This small, informed constituency can then provide the community with a lead-in to other reclaimed water options in the future. Golf course superintendents spread the word informally, and, as golfers see the benefits, the earliest of education campaigns has subtly begun. Later, the same community may choose to introduce an urban system, offering reclaimed water for irrigation use.

Since many reuse programs may ultimately require a public referendum to approve a bond issue for funding reuse system capital improvements, diligently soliciting community viewpoints and addressing any concerns early in the planning process can be invaluable in garnering support. Public involvement early in the planning process, even as alternatives are beginning to be identified, allows ample time for the dissemination and acceptance of new ideas among the constituents. Public involvement can even expedite a reuse program by uncovering any opposition early enough to adequately address citizen concerns and perhaps modify the program to better fit the community.

7.2 Defining the "Public"

Many contemporary analyses of public involvement define "the public" as comprising various subsets of "publics" with differing interests, motivations, and approaches to policy issues. For example, in discussing public participation for wastewater facilities and reuse planning the following publics may be identified: general public, potential users, environmental groups, special interest groups, home owners associations, regulators and/or regulating agencies, educational institutions, political leaders, and business/academic/community leaders. In an agricultural area, there may be another different set of publics including farmers.

For example, several government agencies in California held a Reuse Summit in 1994, at which they endorsed the creation of the public outreach effort by creating the following mission statement (Sheikh *et al.,* 1996):

> "To activate community support for water recycling through an outreach program of educating and informing target audiences about the values and benefits of recycled water."

During that summit they also identified 8 public audiences: Local Elected Officials, Regulatory Agency Staff, General Public, Environmental Community, City Planning Staffs, Agricultural Community, Schools, and Newspaper Editorial Boards.

From the outset of reuse planning, informal consultation with members of each of the groups comprising "the public", and formal presentations before them, should both support the development of a sound base of local water reuse information and, simultaneously, build a coalition that can effectively advocate reuse in the community. Keeping in mind that different groups have different interests at stake, each presentation should be tailored to the special needs and interests of the audience.

If a reuse program truly has minimal impact on the general public, limited public involvement may be appropriate. For example, use of reclaimed water for industrial cooling and processing – with no significant capital improvements required of the municipality – may require support only from regulatory, technical, and health experts, as well as representatives from the prospective user and its employees. Reuse for pastureland irrigation in isolated areas might be another example warranting only limited public participation.

7.3 Overview of Public Perceptions

One of the most tried and true methods of determining the public's perception of reuse programs is surveys. Surveys can determine whether or not there will be a large enough consumer base to sustain a program, if the program will be favorable enough to progress to the conceptual and design stage, and the overall success of the project after implementation. The following projects highlight different survey strategies and results across the nation.

7.3.1 Residential and Commercial Reuse in Tampa, Florida

A survey done by the City of Tampa for its residential reuse project included a direct mailing and public opinion survey. Information was sent to 15,500 potable water customers in the conceptual project area. Out of the pool of potential reuse customers, 84 percent of the residential users and 94 percent of the commercial users in the South Tampa area thought that reclaimed water was safe for residential and commercial landscape irrigation. Of the same group, 84 percent of the residential responders and 90 percent of the commercial responders replied that the project was appealing. The responses met the design criteria of 90 percent participation (Grosh *et al.,* 2002).

7.3.2 A Survey of WWTP Operators and Managers

A study done by Hall and Rubin in 2002 surveyed 50 wastewater operators and managers. Seventy percent of the responders stated that they believed that reuse would be an important part of their operation in 5 years. The majority (66 percent) thought that water reuse should be considered as an element of all water and wastewater expansion facility permits. Ninety percent wanted funding agencies to consider financial incentives to encourage more water reuse. **Table 7-1** lists the survey results (in percentages) to the inquiry for potential use alternatives for reclaimed water.

7.3.3 Public Opinion in San Francisco, California

The City of San Francisco, California, surveyed the general public to measure public acceptance of a proposed reclaimed water project. **Figures 7-1** and **7-2** graphically demonstrate the responses that were collected. The overall majority strongly felt that reclaimed water was beneficial. Figure 7-2 shows that the responders felt positively about all of the proposed uses of reclaimed water: fire fighting, irrigation of golf courses and parks, street cleaning, toilet flushing, and drought protection.

7.3.4 Clark County Sanitation District Water Reclamation Opinion Surveys

Clark County (Las Vegas, Nevada) conducted a series of 4 different surveys. The surveys included a face-to-face intercept survey at the Silver Bowl Park, a direct mail survey with local residents in the Silver Bowl Park area, a direct mail survey to local residents in the Desert Breeze Park vicinity, and face-to-face intercepts with attendees of the EcoJam Earth Day Event. A total of 883 persons participated in the survey (Alpha Communications Inc., 2001).

The majority (63.8 to 90.1 percent) of the responses were very positive, replying that the "…overall benefits of reclaimed water usage are very beneficial." There was a small minority who had concerns with "…environmental safety, bacteria, or germ build-up and general health risks to children" (Alpha Communications Inc., 2001). **Figure 7-3** shows a graphical representation of the average public opinion responses from the 4 surveys regarding reuse for 4 different uses: golf course irrigation, park irrigation, industrial cooling, and decorative water features.

Another portion of the survey asked if there were any benefits of using reclaimed water at park facilities. **Table 7-1** lists the responses.

There is no question that the public's enthusiasm for reuse (as noted in the cited studies) could reflect the hypothetical conditions set up by the survey questions and interviews used rather than signify a genuine willingness to endorse local funding of real programs that involve distribution of reclaimed water for nonpotable use in their neighborhood. Survey results do indicate, however, that, at least intellectually, "the public" is receptive to use of reclaimed water in well thought out programs. The results also support conclusions that this initial acceptance hinges in large measure on:

- The public's awareness of local water supply problems and perception of reclaimed water as having a place in the overall water supply allocation scheme
- Public understanding of the quality of reclaimed water and how it would be used
- Confidence in local management of the public utilities and in local application of modern technology
- Assurance that the reuse applications being considered involve minimal risk of accidental personal exposure

Table 7-1. Positive and Negative Responses to Potential Alternatives for Reclaimed Water

Use	Yes	No
Irrigation of Athletic Fields	84	16
Irrigation of Office Parks and Business Campuses	82	18
Irrigation of Highway Right-of-way	85	15
Residential Landscape Irrigation and Maintenance	74	26
Golf Course Irrigation	89	11
Irrigation of Agricultural Crops	82	18
Irrigation of Crops for Direct Human Consumption	30	70
Vehicle Wash Water	76	24
Concrete Production	90	10
Dust Control	82	18
Stream Augmentation	67	33
Toilet Flushing	80	20
Fire Protection	84	16
Ornamental Ponds/Fountains	56	44
Street Cleaning	87	13
Industrial Process Water	78	22
Wetland Creation	84	16
Pools/Spas	15	85
Potable Reuse – Direct	18	82
Potable Reuse – Indirect	40	60

Adapted from Hall and Rubin, 2002

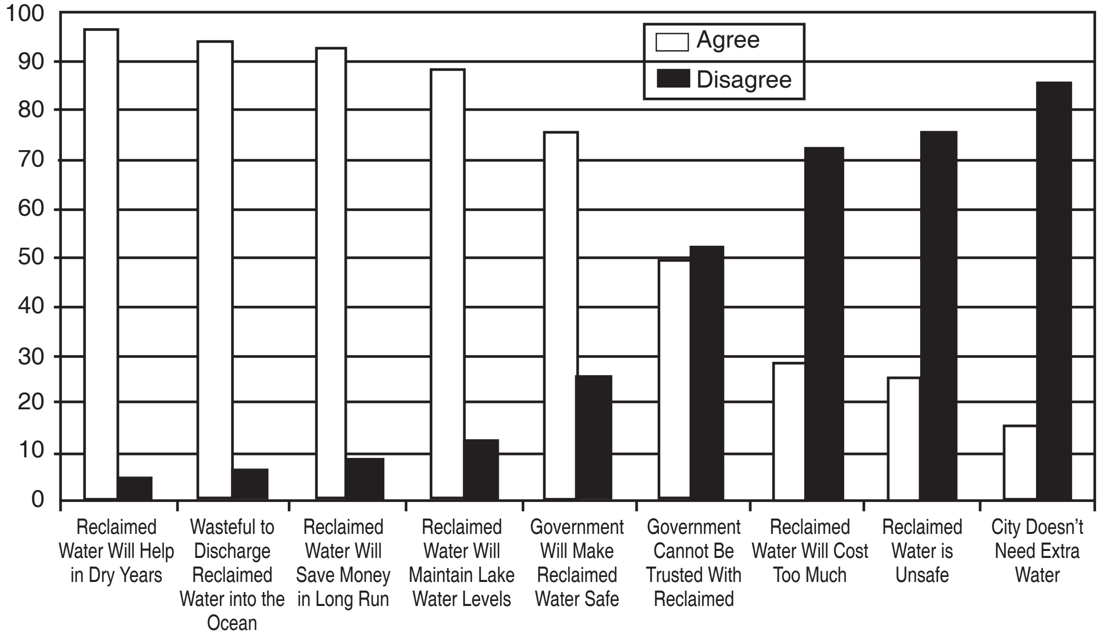
7.4 Involving the Public in Reuse Planning

Even where water reclamation is common, there is a need to establish a flow of information to and from potential reuse customers, so that they can have a clear understanding of the program and provide input regarding their needs and concerns. Equally important is the need to address these concerns and answer any questions in a timely manner. This can help assure the public that their issues are being heard and that reuse planners are being forthcoming in their efforts.

Probably the most important step in encouraging the public acceptance is to establish and communicate the expected project benefits. If the project is intended to extend water resources, then preliminary studies should address how much water will be made available through reclamation and compare the costs to those needed to develop other potable water sources. If reclamation costs are not competitive, then overriding non-economic issues must exist to equalize the value of the 2 sources. When reclamation is considered for environmental reasons, such as to reduce or eliminate surface water discharge, then the selected reuse alternative must also be competitive with other disposal options. Above all, the public must be aware of and understand all of the benefits.

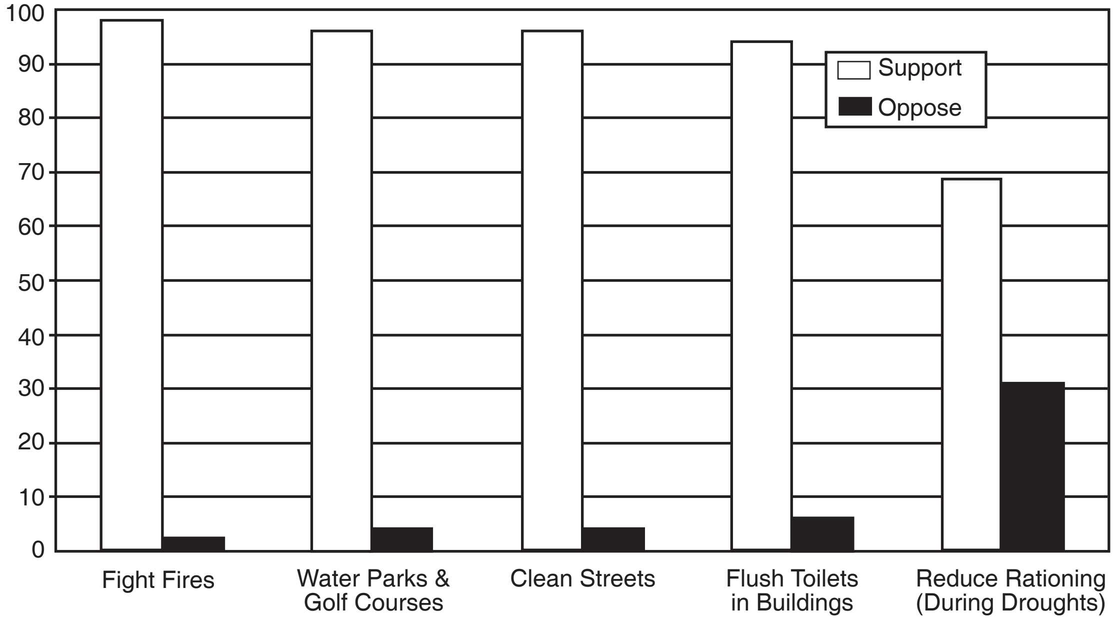
However, most potential reuse programs invoice choices among systems with widely different economical and environmental impacts, which are of varying degrees of

Figure 7-1. Public Beliefs and Opinions



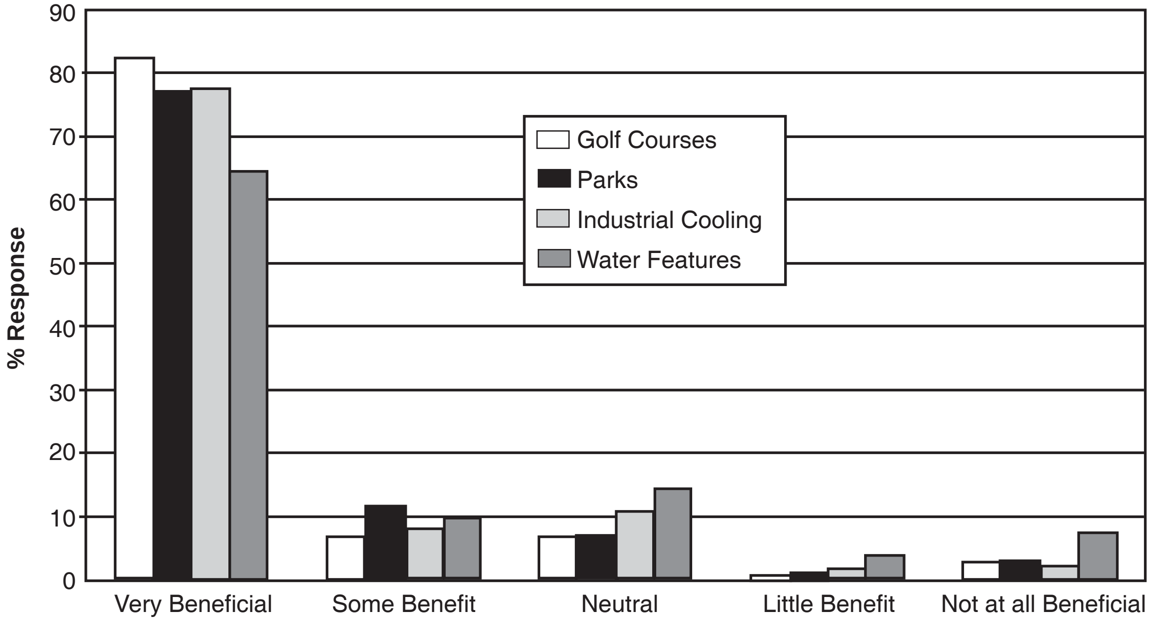
Adapted from Filice 1996

Figure 7-2. Support of Recycled Water Program Activities



Adapted from Filice 1996

Figure 7-3. Survey Results for Different Reuse



Data Source: Alpha Communications 2001

importance to many segments of the public. That is why development of the expected project benefits is so important because once they are firmly established, they become the plants of a public information program – the "why" the program is necessary and desirable. Without such validation, reclamation programs will be unable to withstand public scrutiny and the likelihood of project failure increases. In addition, only after the "why" is established can the "who" and "how" in public involvement truly be determined.

7.4.1 General Requirements for Public Participation

Figure 7-4 provides a flow chart of a public participation program for water reuse system planning.

The following items suggest an example approach that a community might consider in developing a reuse program. Note that information tools will vary depending upon how broad or involved an information program is needed.

- Determine, internally, the community's reuse goals and the associated options and/or alternatives to be further considered.

- Identify any scientific/technical facts that exist, or are needed, to help explain the issues and alternatives. If additional facts or studies are needed, consider beginning them in the earliest stages so that additional scientific data can be made available later in the process. Unanswered questions can damage the credibility of the program effort.

- Create a master list of stakeholders, including agencies, departments, elected officials, potential customers, and others who will be impacted in some way. It might be helpful to identify the level of interest different individuals and groups will have in the reuse planning process.

- Begin public outreach to specific target audiences in the form of informal meetings involving direct contact, limiting the number invited at any one time so that individual discussion is more easily accomplished

- Determine whether a task force or advisory committee is needed. If so, take steps to formally advertise and be sure to include representatives from the target audience groups. Plan a schedule and target date for reaching consensus on reuse alternatives; then plan well-prepared meetings that invite two-way communications. Bring in outside experts, such as scientists, to answer questions when needed.

Figure 7-4. Public Participation Program for Water Reuse System Planning

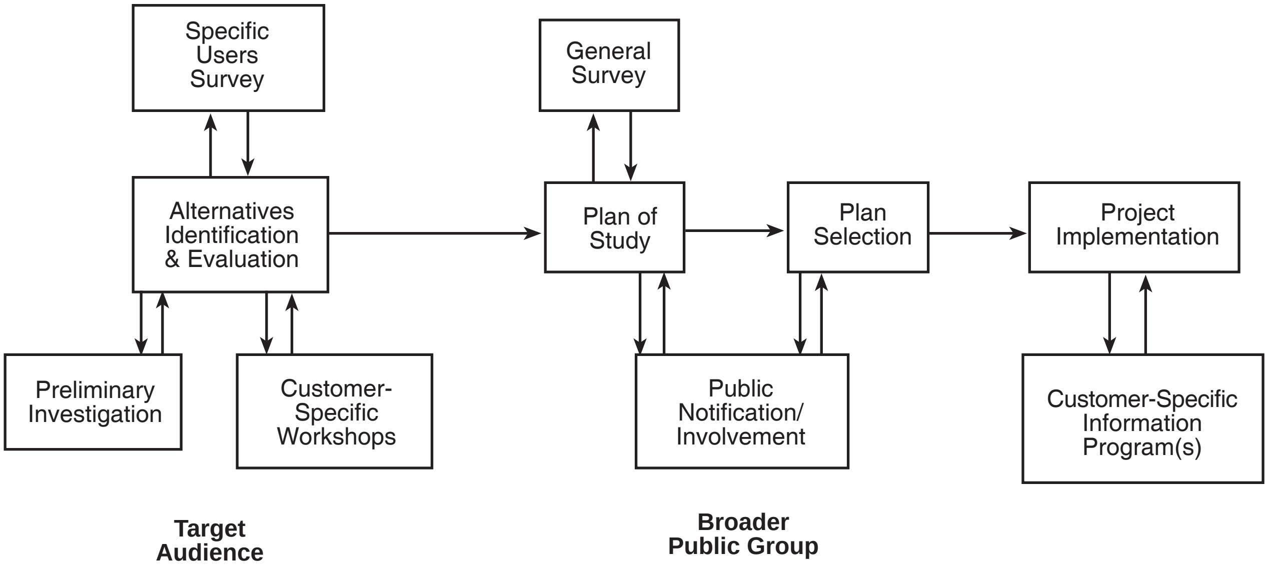


Table 7-2. Survey Results for Different Reuse

Purpose	Tools
Communitywide Education/Information	News media, editorial boards, program web site, traveling exhibits, brochures, educational videos, school programs, open houses
Direct Stakeholder or Citizen Contact	Neighborhood meetings, speeches and presentations to citizen/stakeholder groups, direct mail letters and surveys, program "hotlines" for answering information or managing construction complaints
Formalized Process	Public workshops, public meetings, presentations to elected bodies, public hearings, advisory committees, special task forces

From the task force or advisory committee, the community should be able to identify public issues that need further attention, and determine which additional public information tools will be needed. **Table 7-2** outlines a number of public information tools that can be used in the public participation process.

Once the issues are identified and public reaction is anticipated, the following tools may be useful in conveying information to the broader public:

- Citizen survey. Can be conducted via direct mail or telephone and might be accompanied by media releases to help increase the number of surveys returned or calls answered. In the early stages, a general distribution survey may be helpful in identifying level of interest, potential customers, and any initial concerns that the population might have. Where specific concerns are identified, later public information efforts can be tailored to address them. These tailored efforts could include participation by other public agencies that can provide information on water reuse and regulatory requirements, informal discussions with some potential users to determine interest or fill data gaps, and initial background reports to appropriate local decision- making bodies.

- As the program progresses to alternative identification and evaluation, another survey might be considered. This survey could help confirm earlier results, monitor the effectiveness of the ongoing education program, or target specific users. Note that the percentage of citizens who take the time to participate in a survey varies widely from one community to another. This should not be the only tool relied upon in gathering input.

- Open houses. Advertise periodic public open houses where information is made available and knowledgeable people are on hand to answer questions. Maps, displays, and brief slide demonstrations are all useful open house tools.

- Program website. Increasingly, citizens are turning to websites as important information sources. Such a website can be purely informational or it can invite citizens to ask questions. The website should be updated on a regular basis and can include: its own survey or results of a citizen survey, answers to frequently asked questions, information regarding other successful programs in nearby communities, or a slideshow-style presentation that outlines the program goals and alternatives being considered.

- Media relations. In addition to project news releases, it can be very helpful to spend extra time with reporters who will be covering the topic on a regular basis, providing added background data, plant tours, and informal updates at appropriate times. This helps to provide accurate, balanced reports. The media can also be helpful in making survey data known, and in posting maps of construction areas once program implementation is underway.

- Direct mail updates or occasional newspaper inserts. These updates allow the community to address questions or issues - not relying specifically on a media report.

- Briefings for government officials. Because water reclamation programs often end up with a vote by a city council, county commission, or other elected body, it is vital that each elected official be well-informed throughout the reuse planning process. Therefore, informal briefings for individual officials can be an invaluable tool. These briefings are often conducted prior to public workshops and formal votes, and allow questions to be answered in advance of a larger, public setting.

- Plant or project tours. During the education process, a tour of an existing project that is similar to the one proposed can be an especially useful tool in providing information to key stakeholders, such as an advisory committee, elected body, or the media.

Once a reuse program has been determined, additional public information efforts will be needed throughout the implementation phase, including notification to citizens prior to construction occurring near their home or business. Then, as the reuse program goes on-line, additional media relations and direct mailings will be needed. In the case of urban reuse, this will include information to help homeowners through the connection process.

The City of Tampa's residential reclaimed water project (Florida) is one example of a successful comprehensive public participation program. The City used the services of Roberts Communication to conduct a targeted public education program, which included the following elements (Grosh *et al.,* 2002):

- Opinion leader interviews
- Public opinion survey
- Speakers bureau
- Direct mail to potential customers
- Newsletter article for homeowner association newsletters

7.4.1.1 Public Advisory Groups or Task Forces

If the scope or potential scope of the reuse program warrants (e.g., reclaimed water may be distributed to several users or types of users, or for a more controversial use), a public advisory group or task force can be formed to assist in defining system features and resolving problem areas. In its regulations for full-scale public participation programs, EPA requires that such group membership contain "substantially equivalent" representation from the private (non-interested), organized, representative, and affected segments of the public. It is recommended that, for reuse planning, group membership provide representation from potential users and their employees, interest groups, neighborhood residents, other public agencies, and citizens with specialized expertise in areas (such as public health) that pertain directly to reclamation/reuse.

The advantage of an advisory group or task force is that it offers an opportunity to truly educate a core group that may later become unofficial "spokespersons" for the project. For such a group to be successful, members must see that their input is being put to meaningful use. Depending upon the community need, either an advisory committee or task force may be appropriate. Advisory committees are generally formed for an indeterminate period to continuously provide input regarding issues related to the topic. So, if an advisory committee is formed for reuse water, the committee may be kept as a recommending body to city council, county commission, or other elected body, regarding all future reclaimed water projects or issues. Often, members of the advisory group are designated to serve 2-year terms. With the development of a task force, the objectives are clearly defined and the task force disbands once the objectives have been met. Often, a task force can be a better short-term solution.

Whether a community chooses a task force or advisory committee, it is very important to take steps to institutionalize the group and its activities so that its efforts are formally recognized as meaningful by the elected body. This group can effectively focus on the task at hand—planning and implementation of a reuse program in which the legitimate interests of various sectors of the public have been fully considered and addressed. In order to achieve this, the proposed formation of the advisory group or task force should be publicized to solicit recommendations for, and expression of interest in, membership. Often, the community and its leadership will be aware of candidates who would be ideal to fulfill this role.

Whether a short-lived task force or a longer-term advisory committee, the group's responsibilities should be well-defined. Its meetings should be open to the public at times and places announced in advance. Interpretive meeting minutes should be kept and made available to the public. During an initial meeting, the group's members should designate a single individual who can serve as a contact point for the news media. The group should fully recognize its shared responsibility for developing a sound reuse program that can serve both user requirements and community objectives. In subsequent public meetings, the group will assert its combined role as a source of information representing numerous interests, and an advocate of the reuse program as it gains definition.

7.4.1.2 Public Participation Coordinator

EPA regulations for full-scale public participation programs require appointment of a public participation coordinator – an individual skilled in developing, publicizing, and conducting informal briefings and work sessions as well as formal presentations for various community groups. The appointment of a public participation coordinator helps ensure that one accurate source of information is available, and that individuals who show interest are given an opportunity to provide meaningful input. Such a person, whether an agency staff member, advisory group member or specialist engaged from the larger community, should be thoroughly informed of the reuse planning process, be objective in presenting information, and have the 'clout' necessary to communicate and get fast response on issues or problems raised by citizens involved in the process.

To accomplish this goal, many communities involved in urban and agricultural reuse have created a dedicated reuse coordinator position. The responsibilities of such a position will vary according to specific conditions and preferences of a given municipality. In many programs, the reuse coordinator is part of the wastewater treatment department. However, the position can be associated with the water system, or independent of either utility.

7.4.2 Specific Customer Needs

As alternatives for water reuse are being considered, the customers associated with each alternative should be clearly identified, and then the needs of these customers must be ascertained and addressed. In the past, failure to take this step has resulted in costly and disruptive delays to reclamation projects. Early involvement of citizen stakeholders is a key to program success and is based on tailoring a program to the specific user type and type of reuse system.

7.4.2.1 Urban Systems

In urban reuse programs, the customer base may consist of literally thousands of individuals who may be reached through the local media, publicly advertised workshops, open houses, or neighborhood meetings. Identification of homeowner associations and civic organizations may allow for presentations to a larger number of potential customers at a single time.

The Monterey Regional Water Pollution Control Agency (MRWPCA) is one example of a public information program that reaches a large urban audience. It has an active school education program with classroom demonstrations to about 2,300 children each year. Booths at the County Fair and other local events reach another 7,500 people. Speeches to civic and service groups reach another 900 people. Together with the 800 people who tour the water reclamation plant each year, 5 percent of the service area population is being educated each year. Bimonthly billing inserts add to the local understanding and appreciation of water reclamation.

7.4.2.2 Agricultural Systems

In agricultural reuse programs, the issues of concern may differ from those of the urban customer. In such programs, the user is concerned with the suitability of the reclaimed water for the intended crop. Water quality issues that are of minor importance in residential irrigation may be of significant importance for agricultural production. For example, nitrogen in reclaimed water is generally considered a benefit in turf and landscape irrigation. However, as noted in the Sonoma Case Study in Chapter 3, the nitrogen in agricultural reclaimed water could result in excessive foliage growth at the expense of fruit production. Similarly, while turf grass and many ornamental plants may not be harmed by elevated chlorides, the same chloride levels may delay crop maturation and affect the product marketability, as occurred in the strawberry irrigation study for the Irvine Ranch Water District discussed in Section 3.4.

For these reasons and others, it is necessary to modify the public participation approach used for the urban customer when developing an agricultural program. Agencies traditionally associated with agricultural activities can provide an invaluable source of technical information and means of transmitting information to the potential user. Local agricultural extension agents may prove to be the most important constituency to communicate as to the benefits of reclamation to the agricultural community. The agents will likely know most, if not all, of the major agricultural sites in the area. In addition, they will be familiar with the critical water quality and quantity issues facing the local agricultural market. Finally, the local farmers usually see the extension office as a reliable source of information and are likely to seek their opinion on issues of concern, as might be the case with new reclamation projects. The local extension agent will be able to discuss the issues with local farmers and hopefully endorse the project if they are familiar with the concept of reuse. The local soils conservation service may also prove an important target of a preliminary information program. Lack of endorsement from these agencies can hinder the implementation of agricultural reclamation.

7.4.2.3 Reclaimed Water for Potable Purposes

While “reuse” of water has occurred naturally over the ages, the concept of treating wastewater to a level that is acceptable for drinking is the most difficult type of water reuse to gain public acceptance. In such cases public health and safety issues are of utmost importance and citizen questions will need to be fully addressed. Therefore, a comprehensive public participation effort will be required, initially focusing on the water problems to be addressed, and then turning to a thorough look at possible solutions.

Regulatory agencies, health departments, and other health and safety-related groups will be key audiences throughout the process. These are groups the public turns to for answers; therefore, it is very important to develop strong working relationships. Representatives from local agencies are also most likely to understand the issues that need to be addressed and can provide meaningful input regarding reuse options. Endorsement from these agencies is critical to program acceptance by the public.

7.4.3 Agency Communication

As noted in Chapters 4 and 5, the implementation of wastewater reclamation projects may be subject to review and approval by numerous state and local regulatory agencies. In locations where such projects are common, the procedures for agency review may be well-established. Where reclamation is just starting, formal review procedures may not exist. In either case, establishing communication with these agencies early in the project is as important as addressing the needs of the potential customers. Early meetings may serve as an introduction or may involve detailed discussions of the permitability of a given project. As with all other types of stakeholders, the proposed project must be understood and endorsed by the permitting agencies.

It may also be appropriate to contact other agencies that may still become involved with a public education program. In fact, early coordination with key agencies, such as a community health department, is an important consideration for a couple of reasons. First, the agency may not be well-informed about the community’s reuse goals. Early discussions can help to answer questions and identify issues at a time when the issues can most easily be addressed. Second, because the public often turns to these agencies for information, early meetings will help to ensure that citizens receive accurate, consistent answers. If a citizen were to ask one agency a question and receive a different answer than the community representative gave, credibility of the program can be undermined.

Where multiple departments in the same agency are involved, direct communication with all concerned departments will ensure coordination. It is worthwhile to establish a master list of the appropriate agencies and departments that will be copied on status reports and periodically asked to attend review meetings. And while this communication will be beneficial in developing any reclamation project, it will be critical when specific regulatory guidance on a proposed project does not exist. Such a condition is most likely to occur in states lacking detailed regulations or in states with very restrictive regulations that discourage reuse projects.

7.4.4 Public Information Through Implementation

No matter the type of reclaimed water project, some level of construction will be involved at the implementation stage. Citizens who may not have had an opinion prior to construction could become negative if the process does not go smoothly. This can be especially challenging in urban reuse programs when citizen "disruptions" are more visible. Whenever possible, minimal disruption to sidewalks and driveways should be planned, along with a speedy restoration effort. It will be worthwhile for the community to have a formal construction complaint process in place that offers one phone number to call regarding problems, and a tracking system that documents how quickly complaints are resolved. Public information regarding construction activities can be made available through the local media. The community will also need an information program regarding connections to the system, with emphasis on making the process as simple as possible for each customer.

7.4.5 Promoting Successes

In communities where the use of reclaimed water is new, short-term project successes can become a strong selling point for later, larger programs. Such is the case with communities that may begin an urban program by using reclaimed water in highly visible public medians. Citizens who drive pass these medians are likely to note improvements over time and see "reclaimed water" signs posted at the site. Over time, as a reuse program becomes more established, the public information specialists will need to look for other opportunities to talk about how the program is helping the community. These follow-up information efforts provide an important role in making reuse water a long-term solution for the community.

Reclaimed water has been actively and successfully used in urban applications for more than 30 years. These long-term successes have helped to encourage more and more communities to make use of this resource. As citizens have grown to accept and embrace the use of reclaimed water, a new need for education has arisen because the supply of reclaimed water is limited and should not be wastefully used any more than potable water should not be over-used. The problem of reclaimed water over-use seems to be especially true in communities that do not have metering systems to track the specific amount of water used. Metering systems, and a sliding scale for payment according to the amount used, are examples of approaches that some communities use to encourage conservative use of the reclaimed water. In Cape Coral, Florida, where urban reuse has been in place for more than 10 years, the City launched an education campaign gently reminding citizens to conserve.

7.5 Case Studies

7.5.1 Accepting Produce Grown with Reclaimed Water: Monterey, California

For many years some vegetables and fruits have been grown in foreign countries with reclaimed water and then sold in the U.S. This practice suggests acceptance on the part of the distributors and consumers. In Orange County, California, the Irvine Company has been furrow irrigating broccoli, celery, and sweet corn with reclaimed water for over 20 years.

In 1983, as part of the Monterey Wastewater Reclamation Study for Agriculture (see description in Section 3.8), individuals involved with produce distribution were interviewed regarding the use of reclaimed water for vegetable irrigation. One hundred and forty-four interviews were conducted with:

- Brokers and receivers at terminal markets throughout the U.S. and Canada
- Buyers for major cooperative wholesalers in principal cities
- Buyers, merchandisers, and store managers with small, medium, and large chains

The primary focus of the interviews was the need or desire to label produce grown with reclaimed water. The results are given in **Table 7-3**.

The responses indicated the product would be accepted, and that labels would not be considered necessary. According to federal, state, and local agency staff, the source of the water used for irrigation was not subject to labeling requirements. Produce trade members indicated labeling would only be desirable if it added value to the product. Buyers stated that good appearance of the product was foremost. An abbreviated update of the 1983 survey was conducted in 1995 and led to these same conclusions.

Since 1998, the Monterey Regional Water Pollution Control Agency (MRWPCA) has been providing reclaimed water for nearly 12,000 acres (4,900 hectares) of vegetables and strawberries. Growers, especially those with a world known brand, are reluctant to advertise the source of water used on their crops. They believe the water is as

Table 7-3. Trade Reactions and Expectations Regarding Produce Grown with Reclaimed Water

Reaction or Expectation	Respondents Knowledgeable About Reclaimed Water	Respondents Not Aware of Reclaimed Water
Would Carry	64%	50%
Would Not Carry	20%	25%
Don't Know	16%	25%
TOTAL	100%	100%
Would Not Expect it to be Labeled	68%	67%
Would Expect it to be Labeled	20%	25%
Don't Know	12%	8%
TOTAL	100%	100%

Total Number of Respondents=68
Source: Monterey Regional Water Pollution Control Agency, 2002

good as or better than other irrigation water but are concerned with perception issues. Consequently, 3 approaches are being followed to address these concerns: operating the treatment plant beyond the regulatory requirements, low profile education of local residents, and planning for real or perceived problems with the produce.

MRWPCA strives to meet Title 22 requirements (<2 NTU, >5 ppm chlorine residual, <23 MPN max.) when the water enters the distribution system. This is usually 1 day after being held in an open storage pond following treatment. During the peak growing season, chlorine residual is maintained in the water until it is applied to the crops. The storage pond is sampled for fecal coliform, emerging pathogens, *Clostridium*, and priority pollutants. All the results are shared with the growers via the MRWPCA's website (www.mrwpca.org) and through monthly grower meetings.

MRWPCA has an active school education program with classroom demonstrations to about 2,300 children each year. Booths at the county fair and other local events reach another 7,500 people. Speeches to civic and service groups reach another 900. Along with 800 people coming to tour the water reclamation plant each year, 5 percent of the service area population is being educated each year. Bimonthly billing inserts add to the local understanding and appreciation of water reclamation.

The Water Quality and Operations Committee is a group consisting of project growers, the county health department, and the reclaimed water purveyors. It meets monthly and decides policy issues for the project. That group hired a public relations firm to plan for a crisis, and a crisis communication manual was prepared. The committee is editing the manual, continuing to prepare for different possible scenarios, and preparing to train members on how to deal with the press. The growers are still concerned about perception issues, but are confident that they have prepared for most possibilities.

7.5.2 Water Independence in Cape Coral - An Implementation Update in 2003

The City of Cape Coral, Florida, is one of the fastest growing communities in the country. At 33 years old, this southwest Florida community has a year-round population of more than 113,000 people. However, like many Florida communities, the population fluctuates with more than 18,000 additional residents in the winter months. What makes the City truly unique is its vast developer-planned canal system, with platted lots throughout the community. City planners knew well in advance that they would eventually need to supply water to more than 400,000 residents.

Water supply concerns, coupled with a need to find an acceptable method for ultimately disposing of 42 mgd of wastewater effluent, prompted the City to develop a program called, "Water Independence in Cape Coral" (WICC). WICC includes a unique dual-water system designed to provide potable water through one set of pipes and secondary, irrigation water through a second set of pipes. This secondary water would be provided through reclaimed water and freshwater canals.

Implementation of WICC did not come easy. The WICC master plan was prepared, presented, and adopted by the City with relatively little interest from the public. However, when attempts were made to move forward with

Phase 1 (issuance of special property assessment notices), some members of the public became very vocal and were successful in delaying the project. From the time the City committed to proceed, it took 6.5 years to start up Phase 1. **Table 7-4** lists the chronology of the WICC implementation and highlights the challenges faced by the City in moving forward.

The City began using the secondary water system in 1992. Had a public awareness campaign been launched in the early years, it could have addressed citizen concerns prior to finalizing the special assessment program. Cape Coral's experience provides a valuable lesson to other communities introducing reuse water.

During the first 8 years of using secondary water, Cape Coral was able to conserve more than 4 billion gallons (15 million m^3) of potable water that would previously have been used for irrigation purposes. The system works by pumping reclaimed water from storage tanks to the distribution system. Five canal pump stations transfer surface water from freshwater canals, as needed. Variable speed effluent pumps respond to varying customer demands. The secondary water is treated and filtered before going into the distribution system.

In 2002, the City successfully used secondary water to irrigate more than 15 miles (24 km) of landscaped medians. Other benefits have included the availability of year round irrigation at a reasonable price to customers, the deferred expansion of a City wellfield, the deferred construction of a second reverse osmosis water treatment facility by a number of years, and nearly zero discharge of effluent into the nearby Caloosahatchee River.

As Cape Coral residents came to accept secondary water as an irrigation source, the City found a need to launch an entirely different kind of education campaign. In response to "over-watering" by some customers and concerns by regulatory agencies, the City began to enforce limited watering days and times, just as with potable water. The City's new education campaign underscored the message that secondary water should be recognized as a resource, not a "disposal issue." The City created a friendly "Cape Coral Irrigator," using a smiling alligator,

Table 7-4. Chronology of WICC Implementation

November 1985	City WICC report prepared WICC concept is born
January 1988	WICC master plan adopted
April 1988	Assessment hearing with 1,200 vocal citizens WICC program stopped
November 9, 1988	City Council election Pro-WICC/Anti-WICC campaign Low voter turnout/Anti-WICC prevailed
November 1988 - October 1989	Deadlocked City Council State water management threatens potable allocation cutback Supportive rate study Supportive citizen's review committee Requested increase to potable water allocation denied
November 1989	WICC referendum 60% voter turnout WICC wins 2-to-1
December 1989	Second assessment hearing
February 1990	Construction started for Phase I
March 1992	Phase 1 starts up
September 1992	Phase 2 start up is scheduled
October 1994	Phase 3 start up is scheduled

to remind homeowners about dry season watering times and good conservation practices. The City also created an Irrigator Hotline for people to call to confirm watering schedules, and the City's Code Enforcement began issuing citations to violators to make the message clear.

As Cape Coral continues to grow, the City is looking to expand its secondary system at the same time that crews bring water and sewer service to new areas of this 114-square-mile (295-km^2) community. In another creative endeavor, the City is working to increase the supply of secondary water through weir improvements by seasonally raising weirs to store more water in the canals. These weir improvements may make it possible to supply secondary water to an even larger customer base. Cape Coral has one of the largest, fully integrated water management systems in the country and will bear watching in the future.

7.5.3 Learning Important Lessons When Projects Do Not Go as Planned

Over the last decade, reclaimed water proponents have been highly successful in convincing the public about the benefits of reclaimed water for irrigation. That "hurdle" has, for the most part, been surpassed. But public questions and concerns continue to emerge about using reclaimed water for anything related to potable supplies. Today, science and technology make it possible to treat reclaimed water to drinking water standards. But, even as an indirect water supply source, case studies continue to find hesitation by citizens to embrace highly treated reclaimed water as a potable water source. This is especially true when other water supply options become available. Over time, and as more successes in the potable reclaimed water arena are achieved, this hurdle may also be surpassed.

The following 2 case studies illustrate some of the challenges that can emerge as programs strive to move forward from the conceptual stage.

7.5.3.1 San Diego, California

In 1993, the City of San Diego began exploring the feasibility of using highly treated wastewater, or reclaimed water, to augment imported water supplies. The concept of this "Water Repurification Project" was to treat reclaimed water to an even higher standard and then pipe it into a surface water reservoir. There, the reclaimed water would blend with the raw water supply, thus increasing the water supply available.

Some positive public involvement efforts undertaken by the Water Repurification Project team included:

- Convening a public advisory committee early in the project's development, which included a broad cross section of community interests

- Engaging members of the advisory committee and others, including the Sierra Club, County Medical Society, and Chamber of Commerce, to speak on behalf of the project

- Developing easy-to-understand information materials and disseminating them widely to potential stakeholders

Making presentations to community groups and held numerous workshops and open houses

- Taking members of the public and key stakeholders on tours of the pilot plant where taste tests were held using repurified water

- Briefing policy-makers and their staffs

While the project team worked to educate and involve stakeholders in the process from the early planning stages, the following "outside" factors emerged and may have influenced public perception:

- Once the project moved from concept to design, the City of San Diego's wastewater department took over as the lead agency. This may have served to portray the project as a wastewater disposal solution rather than a water supply solution.

- *Lesson to consider*: If possible, stay with the same project team, especially leadership, from inception through completion. Keep the project goal clear and unchanging. Try to avoid sending mixed messages.

- During the 5 years from concept to design, another water supply alternative emerged. Proponents of an agricultural water transfer positioned it as a superior alternative to indirect potable reuse and launched an aggressive promotional campaign. In fact, the 2 projects were complementary, one providing a new source of imported water, the other a locally controlled water source.

  Lesson to consider: If a new alternative is proposed in a public forum, it needs to be formally recognized and evaluated before the original or an enhanced concept can move forward. Otherwise, the credibility of the original concept may be harmed. In some instances, ideas can be blended through public involvement to develop a more tailored community solution. The goal is to partner with others wherever possible and to avoid an "us versus them" environment.

- The time when the project was ready for final approval from the San Diego City Council coincided with several competitive elections. The project became a political issue. Key votes were delayed until after the election.

  Lesson to consider: Much time is often dedicated to educating community leaders about a project. Elections can disrupt the timing of implementation because added time is then needed to educate new leaders. When possible, big picture planning should consider key election dates, timing project deadlines and approvals prior to any major shifts on a council or commission.

- A State Assembly member running for re-election called for special state hearings on the project, providing a forum for the candidate's allies to attack the project. The same candidate sent a direct-mail "survey" to constituents asking if they supported "drinking sewage." An underdog City Council candidate raised the issue of environmental justice by stating, inaccurately, that while the wastewater source was the affluent part of the city, the water recipients were in lower economic and ethnically diverse neighborhoods. Even though this was not true, the misinformation spread with the help of local radio talk show personalities and African-American activists. Several African-American ministers appeared at City Council hearings to protest politicians "using them as guinea pigs."

  Lesson to consider: If the public hears a particular "fact" as little as 3 times, then, regardless of whether or not the information is true, this "fact" will begin to be perceived as truth. This is why it is so important to correct inaccuracies whenever possible, as quickly as possible. If, for instance, a newspaper article provides incorrect facts about a project and no one calls the reporter to correct the story, then the report is filed in the newspaper archives as factual. The next time a story is needed about the project, a different reporter then uses the previous story for background information. This article is very likely to repeat the wrong information.

- Even after briefings, the lead editorial writer for water issues at *The San Diego Union-Tribune* felt any kind of water reuse was too costly and ill advised. News reporters borrowed the "Toilet to Tap" description (used by media covering a groundwater project in Los Angeles) in their ongoing coverage.

  Lesson to Consider: Developing ongoing relationships with knowledgeable reporters and editorial boards is critical.

- The National Research Council issued a report on indirect potable reuse just prior to the project's consideration by the San Diego City Council. While the report was largely favorable, the executive summary included a statement that indirect potable reuse should be considered an "option of last resort." That comment made national news and was viewed as scientific validation that the project was unsafe.

- Spurred by local media coverage and direct mail from political candidates criticizing the project, a group of County residents formed to actively oppose the project. The "Revolting Grandmas" attended all hearings and public meetings to speak against the project and wrote letters to the media and elected officials. Members of the Revolting Grandmas lived outside the City's jurisdiction and, therefore, had not been included on project mailing lists to receive accurate information for the past 5 years.

  Lesson to Consider: While it may be impossible to identify every stakeholder group in the process, this situation highlights just how critical early identification of a complete list of stakeholders can be.

- A private developer of gray water systems attacked the project repeatedly with elected officials and the media, claiming gray water was a superior water supply option. The company president argued gray water was safer and more cost-effective than indirect potable reuse.

  Lesson to Consider: Sometimes, providing a direct response to a party with an opposing view can be the correct response. But, at other times, providing a response may serve to validate the other person's claims in the eyes of the public. It is important to evaluate the level of response needed on a case-by-case basis.

7.5.3.2 Public Outreach May not be Enough: Tampa, Florida

In the late 1990s, the City of Tampa, Tampa Bay Water, and the SWFWMD, in cooperation with the EPA, studied the feasibility of developing a water purification project for the area. Reclaimed water, treated further at a supplemental water reclamation treatment facility, would be blended with surface water and treated again at the City's water treatment facility. A public outreach program was developed to enhance and improve the public's understanding of the region's water problem, its long history of conflict over water issues, and public perceptions about government and indirect potable reuse. While there were significant challenges to overcome, a public information program began to make headway through the use of the following efforts:

- Identified and interviewed key stakeholders, conducted focus groups, and conducted a public opinion survey
- Developed project fact sheets, frequently asked questions materials, and brochures
- Drafted a comprehensive communication plan for the project
- Formed a public working committee and developed its operating framework
- Developed a project video, website, and layperson's guide to the Independent Advisory Committee's recommendations.
- Supported the Ecosystem Team Permitting process that resulted in permit issuance
- Conducted public meetings, open houses, and workshops

Although the outreach program reached a broad audience and the project was permitted, it has yet to be implemented. Several factors contributed to the lack of implementation, including a lack of support among agency policymakers and senior staff. Specific examples include:

- Policymakers viewed the project as a choice among seawater desalination, creating a new reservoir in an old phosphate pit, and developing the purified water project. Many policymakers considered desalination the preferred option.
- The City of Tampa Department of Sanitary Sewers was the main project proponent, positioning the project from the wastewater side. The City of Tampa Water Department was not actively involved.
- A general manager of a local water agency vocally opposed the project. Tampa Bay Water, the region's water agency, did not speak out to counter the opposition.
- A National Research Council report critical of indirect potable reuse was released just prior to when the Tampa Bay Water Board was called upon to approve the project. The report created a perception that the scientific community was not in favor of indirect potable reuse.

The Tampa project shows the importance of gaining support of policymakers, senior staff and elected officials. It may be worthwhile to consider these among the first target audiences, before working toward a broader public involvement effort.

7.5.4 Pinellas County, Florida Adds Reclaimed Water to Three R's of Education

When Pinellas County Utilities renovated the South Cross Bayou Water Reclamation Facility, the department saw an opportunity to use the new facility as a learning laboratory to teach "real-life" science to students and other County residents. The effort to make the vision a reality began more than a year ago with the construction of an Educational/Welcome Center that is now home to a multifaceted, hands-on educational program.

Initially focusing on high school science students and adult visitors, utility officials worked closely with County high school teachers to develop "Discover a Cleaner Tomorrow" as an appropriate curriculum to enhance classroom learning. The curriculum was designed to support National Science Standards, Sunshine State Standards, and student preparedness for the Florida Comprehensive Assessment Test (FCAT) tests. Through a partnership with the Pinellas County School Board, a certified science educator modifies the curriculum for each visiting class and teaches the scientific principles and methods involved in water reclamation.

Before they visit the South Cross Bayou site, students are introduced to the topic of wastewater treatment through an animated video focusing on the role of bacteria. The video sets the tone for serious learning through humor in the light-hearted production. When they arrive at the site, students are introduced to the facility tour with a second short feature, a sequel to the classroom video. A third video was developed for the general public. Titled "Undissolved Mysteries," it features a detective/narrator who roams through the facility uncovering the mysteries of water reclamation.

After the video presentations, visitors board a tram that transports them through the 35-acre site. Hands-on investigation helps students and other visitors gain a better understanding of wastewater treatment processes.

Students test the wastewater at 2 different locations for dissolved oxygen, nitrates, nitrites, and total suspended solids. They compare their results with those from the professional on-site laboratory, as well as those from other high school groups, adding a competitive element to the tour. Students must each complete an exercise and observation notebook as they take the tour, creating accountability in meeting specific learning objectives.

Visitors to the facility develop a better understanding of the science involved in water reclamation, the role citizens play in managing limited water resources, the importance of clean water, and the range of career opportunities in wastewater treatment and management.

7.5.5 Yelm, Washington, A Reclaimed Water Success Story

The City of Yelm, Washington, boasts an $11 million water reclamation facility that has gained statewide recognition and become a local attraction. Yelm recycles 200,000 gpd (760 m^3/d) of water, with plans to eventually recycle 1 mgd (3,800 m^3/d). The system has been producing Class A reclaimed water since its inception in August 2001; however, the jewel of the facility is an 8-acre (3-hectare) memorial park and fishing pond. At the park, a constructed wetlands system de-chlorinates, re-oxygenates, and further cleans, screens, and moves the water through a wetland park of several ponds, including a catch-and-release fishing pond stocked with rainbow trout. City representatives say the park has become a good place for fishing and viewing wildlife. There's even been a wedding held on site. The City also uses the reclaimed water for irrigation at a middle school and a number of churches. The water is also used to wash school buses and to supply a number of fire hydrants.

Yelm is actively promoting public awareness about reclaimed water. Twenty-five elementary and middle school students entered a city-sponsored contest to see who could come up with the most creative water reuse mascot. The winning mascot, designed by a fifth grader, was a purple pipe aptly named, "Mike the Pipe." Students and teachers then took the concept a step further and created an interactive skit using Mike the Pipe and other characters to talk about what can be done with water that is poured down a drain. Some of the other characters included, "Water Sprite," "Sledge," and "Little Bug."

The City of Yelm Water Reclamation Facility has won awards from the American Public Works Association, the Association of Washington Cities, and, in 2002, the Department of Ecology presented the City with an Environmental Excellence Award.

7.5.6 Gwinnett County, Georgia – Master Plan Update Authored by Public

Population and economic growth, as well as an extended drought, forced Gwinnett County, Georgia, to reassess its water strategy. While simultaneously building the 20-mgd North Advanced Water Reclamation Facility (NAWRF), the county also initiated a multi-stakeholder program to update its *Water and Wastewater Master Plan* in order to combat growing water problems.

The NAWRF is an 11-step reclamation facility that includes primary, secondary, and advanced treatment as well as a 20-mile (32-km) pipeline to discharge plant effluent to the Chattahoochee River. Unit processes at the plant include: clarifying tanks, biological treatment, membrane filters, sand and activated carbon filters, and ozone gas disinfection. During construction, projections led the County to begin plans to renovate the plant to double its capacity to 40 mgd (1,750 l/s).

As part of the multi-stakeholder program to update the master plan, the county created an Advisory Panel. The panel, created in 1996, had meetings facilitated by the Gwinnett County Department of Public Utilities (DPU) with assistance from an environmental consulting firm. Polls were held at public meetings to identify 7 categories of stakeholder groups (Hartley, 2003):

- Homeowner associations
- Business community
- Development interests
- Large water users
- Gwinnett County cities
- Environmental organizations
- Citizens-at-large

Representatives were selected from each of these stakeholder groups and were responsible for attending meetings and conveying information to and from their respective groups. Public meetings were held the first Tuesday of each month for 18 months. The following list of goals and objectives were developed by the Advisory Panel throughout the 18-month discourse (Hartley, 2003):

- Improve reliability of water and sewer system
- Develop strong maintenance and rehabilitation programs

- Protect public health and the environment
- Plan for water and sewer capacity proactively
- Minimize the negative impact of new facilities on neighborhoods and the environment
- Develop alternate water sources
- Pursue regional opportunities
- Manage water and wastewater demand
- Provide a high level of service at an optimum cost

One of the major items of dissent among the regulatory agencies, Gwinnett County, and members of “the public” was effluent disposal from the NAWRF. The original plant included a pipeline to discharge effluent to the Chattahoochee River; however, fears of low quality effluent and recent raw sewage spills and fish kills led many groups and individuals to be against discharge to the river. The second alternative was to discharge effluent to Lake Lanier, which feeds the local water treatment plant, in turn, a form of indirect potable reuse. And although the state did approve discharge into Lake Lanier, it is illegal in the State of Georgia to perform direct potable reuse (Hartley, 2003).

The Advisory Panel recommended the following items for water supply (Hartley, 2003):

- Preference for the continued use of Lake Lanier as a water supply source in the near-, mid-, and long-term
- Blended reuse was considered a secondary alternative in the long-term

The group created a second set of recommendations for wastewater (Hartley, 2003):

- Given the quality of treated wastewater effluent from the NAWRF, nonpotable reuse should be “pursued vigorously” through all time periods
- Continue to seek conversions from septic tanks to public wastewater treatment
- Discharge into the Chattahoochee River in the near-term was preferred, with a second option being discharge into Lake Lanier
- Increased preferences for blended reuse in reservoirs for the mid- and long-term planning horizons

These items were included in the update to the master plan that the Advisory Panel members “…actively wrote and edited…” (Hartley, 2003).

In addition to the creation of the Advisory Panel, Gwinnett County created a separate Citizen Advisory Board to oversee responsibilities at the NAWRF, especially proper operations and meeting effluent limits. This board was created in response to the concern that lower-standard effluent would have detrimental effects on the Chattahoochee River and Lake Lanier.

“While there were a few common members with the master planning process Advisory Panel, the Citizen Advisory Board is in independent group with a distinct role. It serves as a communication channel between the public and the utility. The Citizen Advisory Board controls its own $50,000/year budget. The Citizen Advisory Board has spent the funds on sampling, technical review of plans and designs, and other oversight activities” (Hartley, 2003).

The Citizen Advisory Board has been successful in both facilitating communications with other citizens, as well as being instrumental in ensuring premium operations and maintenance at the NAWRF. Most recently they succeeded in adding a new resolution to include annual budgeting for the retraining of the operations and maintenance staff at the plant (Hartley, 2003).

7.5.7 AWWA Golf Course Reclaimed Water Market Assessment

In 1998, the AWWA Water Reuse Committee commissioned a study to survey golf course superintendents regarding their perceptions and experiences using reclaimed water. With the increasing need to turn to reclaimed water for non-domestic uses, the water industry was interested in determining if the existing systems providing reclaimed water to golf courses were satisfactory or needed improvement so that this information could be used by providers when developing future reclaimed water systems.

A survey creation group was formed with members of the USGA Green Section, certified golf course superintendents, and a member of the University of Nevada at Las Vega (UNLV) research staff. This group developed a 37-question survey focused primarily on the technical aspects of water quality issues, irrigation system issues, management issues, provider issues, and the perceptions of golfers, superintendents, and the public.

The survey was beta tested in 2000 with the AWWA CA/NV Recycled Water Committee and the NWEA user subcommittee of Reuse Nevada to ensure that the time commitment and survey content were appropriate. A website was built to disseminate the survey, providing a readily available place for soliciting input from superintendents across the nation. The website, www.gcrwa.com, was opened in September of 2000 and the necessary programming was completed to allow the survey data to be downloaded to a secure database so that the results could be evaluated.

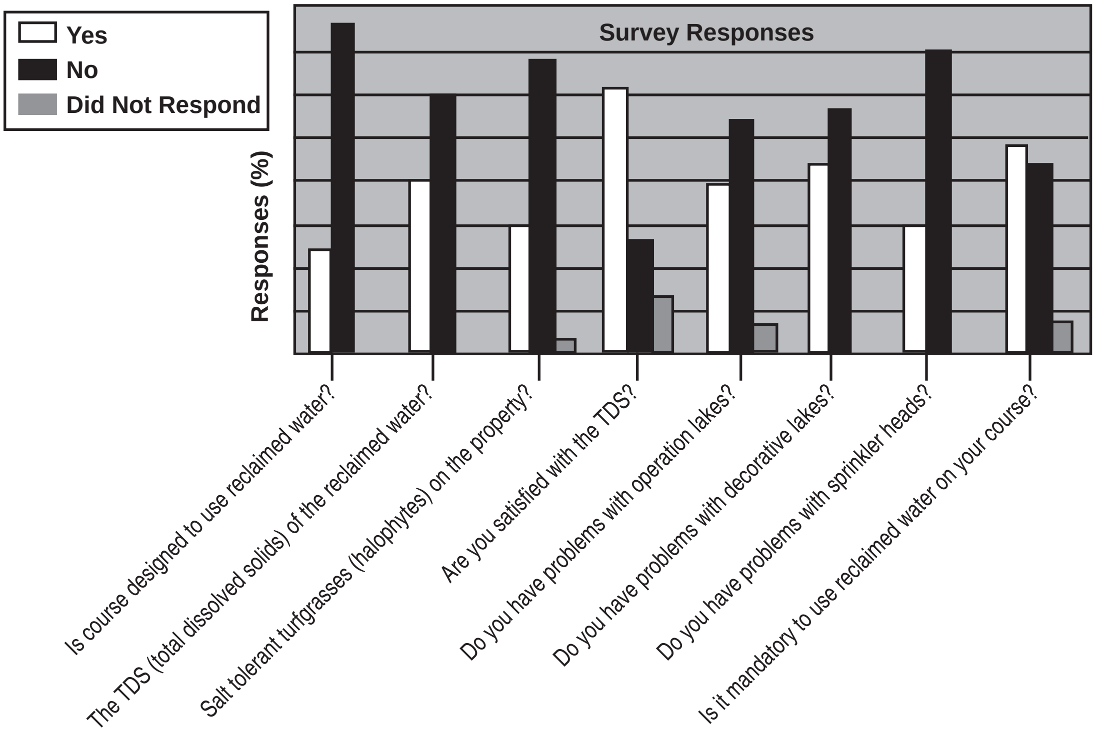
Since January 2003, data has been received from 15 states and British Columbia with the majority of the survey responses coming from Florida, Arizona, and Nevada. Knowing that the USGA list of effluent-using golf courses in 1994 numbered 220 and the number in Southern Nevada alone has grown from 5 to 17 since then, it is estimated that the number of golf courses in the U.S. that use reclaimed water might easily exceed 300 today. Based on this expected sample population, the most significant observation has been the slow response rate from golf course superintendents — only 88 have been received. Internet responses as of January 2003 numbered 62, while returns by fax or mail number 26, indicating that 30 percent of the superintendents either do not have access to the Internet or prefer to respond with hard copy.

The survey responses have come from private courses (47 percent) and public courses (53 percent). Most of the courses (78 percent) were standard 18-hole courses and ranged between 660 and 7,200 yards (600 and 6,580 meters) in length. About 55 percent of the courses use reclaimed water all or part of the time. The remaining 45 percent of the courses use potable, well, storm, canal, river water, or combinations thereof to irrigate their courses.

Significant to the intent of the survey, was the response regarding the opinions of golfers, nearby residents, and superintendents to the use of reclaimed water. Negative comments about reclaimed water appear to be limited to about 10 percent of each of the groups, with odors being the only repetitive comment. The overwhelming majority (90 percent) appears to be very positive and supportive of reclaimed water use. Algae, pondweeds, and odors were the 3 most troublesome problems for superintendents associated with both reclaimed water irrigation systems and aesthetic ponds.

Irrigation quantity and timing was most often influenced by turf color, followed by soil sampling and on-site weather stations. Total dissolve solids (TDS) is generally claimed to be a large concern with turf irrigation water, so it was interesting to find that only 31 percent of

Figure 7-5. Survey Reponses



the survey respondents claimed to know what the actual TDS of their water was, yet 59 percent were either satisfied or dissatisfied. Satisfied outnumbered the dissatisfied by a ratio of 2 to 1. A graphical representation of the survey responses is presented in **Figure 7-5**.

7.6 References

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Chapter 8

Water Reuse Outside the U.S.

The need for alternative water resources, coupled with increasingly stringent water quality discharge requirements, are the driving forces for developing water reuse strategies in the world today. Water reuse enables practitioners to manipulate the water cycle, thereby creating needed alternative water resources and reducing effluent discharge to the environment. The growing trend is to consider water reuse as an essential component of integrated water resources management and sustainable development, not only in dry and water deficient areas, but in water abundant regions as well. In areas with high precipitation where water supply may be costly due to extensive transportation and/or pumping, water reuse has become an important economic alternative to developing new sources of water.

Reuse of wastewater for agricultural irrigation is practiced today in almost all arid areas of the world. Numerous countries have established water resources planning policies based on maximum reuse of urban wastewater. In many dry regions, particularly in developing countries in Asia, Africa, and Latin America, unplanned use of inadequately treated wastewater for irrigation of crops continues today and is often confused with planned and regulated reuse. This major health concern makes it imperative to governments and the global community to implement proper reuse planning and practices, emphasizing public health and environmental protection, during this era of rapid development of wastewater collection and treatment. Within the next 2 decades, 60 percent of the world's population will live in cities. As increasingly ambitious targets for sewage collection are pursued, massive and growing volumes of wastewater will be disposed of without treatment to rivers and natural water bodies. The challenges will be particularly acute in mega-cities (cities with a population of 10 million or more), over 80 percent of which will be located in developing countries.

This chapter provides an overview and examples of water reuse in countries outside of the U.S., including the implementation of reuse in developing countries where the planning, technical, and institutional issues may differ considerably from industrialized countries.

8.1 Main Characteristics of Water Reuse in the World

Increased water shortages and new environmental policies and regulations have stimulated significant development in reuse programs in the past 20 years. According to the conclusions of various water reuse surveys (Lazarova *et al.,* 2001 and Mantovani *et al*., 2001), the best water reuse projects, in terms of economic viability and public acceptance, are those that substitute reclaimed water in lieu of potable water for use in irrigation, environmental restoration, cleaning, toilet flushing, and industrial uses. The main benefits of using reclaimed water in these situations are conservation of water resources and pollution reduction.

A project commissioned by the Water Environment Research Foundation (WERF), Mantovani *et al*. (2001) surveyed nonpotable water reclamation planning and management practices worldwide. The study reviewed 65 international nonpotable water reuse projects to document planning and management approaches for agricultural, urban, and industrial water reuse projects in both advanced and developing countries in the arid and semi-arid belts around the globe. The survey findings confirmed that in addition to operational performance, sound institutional arrangements, conservative cost and sales estimates, and good project communication are the basis for project success. By the same token, institutional obstacles, inadequate valuation of economic benefits, or a lack of public information can delay projects or cause them to fail.

Table 8-1 shows the average volumes of reclaimed water produced in several countries, as well as the relative contribution of water reuse to the total water demand. Recent projections show that in Israel, Australia, and Tunisia, the volume of reclaimed water will satisfy 25 percent, 11 percent, and 10 percent, respectively, of the total water demand within the next few years (Lazarova *et al.,*

Table 8-1. Sources of Water in Several Countries

Country	Total Annual Water Withdrawal			Annual Reclaimed Water Usage			Reclaimed Water as Percent of Total
	Year	Mm^3	MG	Year	Mm^3	MG	
Algeria	1990	4,500	1,188,900	-	-	-	-
Bahrain	1991	239	63,144	1991	15	3,963	6%
Cyprus	1993	211	55,746	1997	23	6,077	11%
Egypt	1993	55,100	14,557,420	2000	700	184,940	1%
Iran	2001	81,000	21,400,200	1999	154	40,687	0.20%
Iraq	1990	42,800	11,307,760	-	-	-	-
Israel	1995	2,000	528,400	1995	200	52,840	10%
Jordan	1993	984	259,973	1997	58	15,324	6%
Kuwait	1994	538	142,140	1997	80	21,136	15%
Kyrgyzstan	1990	11,036	2,915,711	1994	0.14	37	0%
Lebanon	1994	1,293	341,611	1997	2	528	0.20%
Libya	1994	4,600	1,215,320	1999	40	10,568	1%
Morocco	1991	11,045	2,918,089	1994	38	10,040	0.30%
Oman	1991	1,223	323,117	1995	26	6,869	2%
Qatar	1994	285	75,297	1994	25	6,605	9%
Saudi Arabia	1992	17,018	4,496,156	2000	217	57,331	1%
Syria	1993	14,410	3,807,122	2000	370	97,754	3%
Tajikistan	1989	12,600	3,328,920	-	-	-	-
Tunisia	1990	3,075	812,415	1998	28	7,398	1%
Turkey	1992	31,600	8,348,720	2000	50	13,210	0%
Turkmenistan	1989	22,800	6,023,760	-	-	-	-
U. A. Emirates	1995	2,108	556,934	1999	185	48,877	9%
Yemen	1990	2,932	774,634	2000	6	1,585	0%

Sources: Adapted from World Bank, 2001 with updates from Hamdallah, 2000.
Note: (-) indicates that data was not available.

2001). In Jordan, reclaimed water volumes must increase more than 4 times by the year 2010 in order to meet demands. By 2012, the volume of reclaimed water in Spain will increase by 150 percent. The reclaimed water volume in Egypt is expected to increase by more than 10 times by the year 2025. A number of countries in the Middle East are planning significant increases in water reuse to meet an ultimate objective of reusing 50 to 70 percent of the total wastewater volume.

8.2 Water Reuse Drivers

The main drivers for water reuse development worldwide are:

- **Increasing water demands** to sustain industrial and population growth. This is the most common and important driver for dry and water-abundant regions in developed, developing, and transitional countries.
- **Water scarcity and droughts,** particularly in arid and semi-arid regions. In this case, reclaimed water is a vital and drought-proof water source to ensure economic and agricultural activities.
- **Environmental protection and enhancement** in combination with **wastewater management needs** represent an emerging driver, in a number of industrialized countries, coastal areas, and tourist regions. In areas with more stringent wastewater discharge standards, such as in Europe, Australia, and South Africa, wastewater reuse becomes a competitive alternative to advanced water treatment from both economic and environmental points of view.
- **Socio-economic factors** such as new regulations, health concerns, public policies, and economic incentives are becoming increasingly important to the implementation of water reuse projects. For example,

the increase in the cost of potable water will help promote the implementation of wastewater reuse.

- **Public health protection** is the major driver in developing countries where lack of access to fresh water supplies coupled with high market access in urban and peri-urban areas, drives untreated reuse in agriculture. Public health protection and environmental risk mitigation are key components of any reuse program under these conditions.

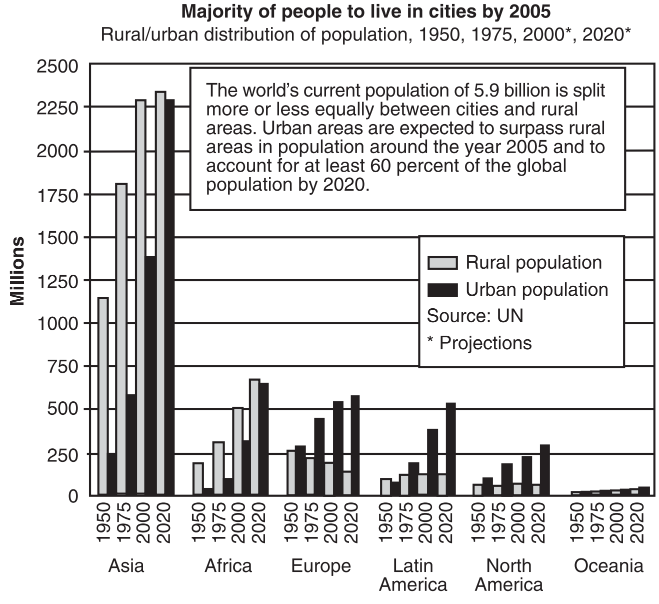
8.2.1 Increasing Water Demands

Population growth, urbanization, and industrial development contribute to water shortages by perpetually pushing up demand. In addition, these same factors increase water pollution, add to potable water treatment costs, and most likely, have adverse health effects. Urban growth impacts in developing countries are extremely pressing. Whereas only 1 in 3 mega-cities were located in developing countries in 1950, in the year 2002, 14 of 22 such cities were in developing countries. By 2020, more than half the total population of Asia, Africa, and Latin America will be living in cities, and all of these cities will need additional water supplies. (See **Figure 8-1**).

8.2.2 Water Scarcity

The most common approach used to evaluate water availability is the **water stress index**, measured as the annual renewable water resources per capita that are available to meet needs for domestic, industrial, and agricultural use. Based on past experiences in moderately developed countries in arid zones, renewable freshwater resources of 1,700 m^3/capita/year (0.45 mg/capita/year) has been proposed as the minimum value at which countries are most likely to begin to experience ***water stress,*** which may impede development and harm human health (Earth Trends, 2001). Below 1,000 m^3/capita/year (0.26 mg/capita/year) of renewable freshwater sources, **chronic water scarcity** appears. According to some experts, below 500 m^3/capita/year (0.13 mg/capita/year), countries experience **absolute water stress** and the value of 100 m^3/capita/year (0.026 mg/capita/year) is the **minimum survival level** for domestic and commercial use (Falkenmark and Widstrand, 1992 and Lazarova, 2001). Projections predict that in 2025, 2/3 of the world's population will be under conditions of moderate to high water stress and about half of the population will face real constraints in their water supply.

Figure 8-1. World Populations in Cities


Majority of people to live in cities by 2005
Rural/urban distribution of population, 1950, 1975, 2000*, 2020*

The world's current population of 5.9 billion is split more or less equally between cities and rural areas. Urban areas are expected to surpass rural areas in population around the year 2005 and to account for at least 60 percent of the global population by 2020.

Source: United Nations 2002

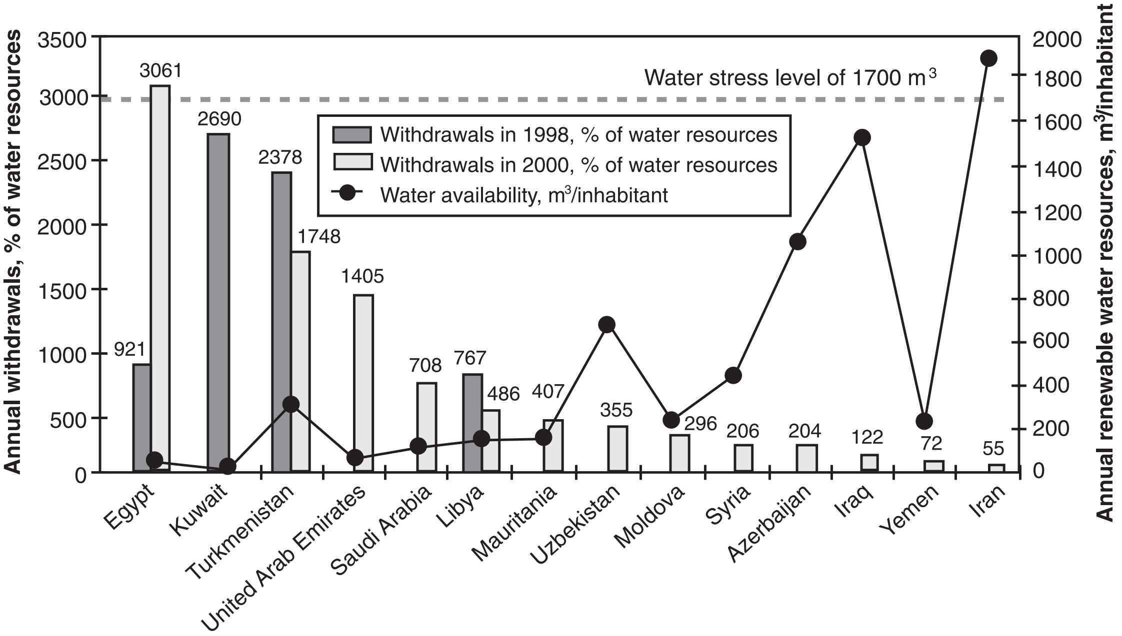
Population Action International has projected the future water stress index for 149 countries and the results indicate that 1/3 of these countries will be under water stress by 2050. Africa and parts of western Asia appear particularly vulnerable to increasing water scarcity. This data also shows that a number of Middle Eastern countries are already well below the absolute water stress of 500 m^3/capita/year (0.13 mg/capita/year) and by 2050 will reach the minimum survival level of 100 m^3/capita/year (0.026 mg/capita/year) for domestic and commercial use. In addition, numerous nations with adequate water resources have arid regions where drought and restricted water supply are common (north-western China, western and southern India, large parts of Pakistan and Mexico, the western coasts of the U.S. and South America, and the Mediterranean region).

A high concentration of population within individual countries also causes water stress. The North China Plain (surrounding Beijing and within the river basins Hai, Huai, and Yellow River) contains most of the country's population, such that the water availability is only about 5 percent of the world average, while China, as a whole, has about 25 percent of the world average.

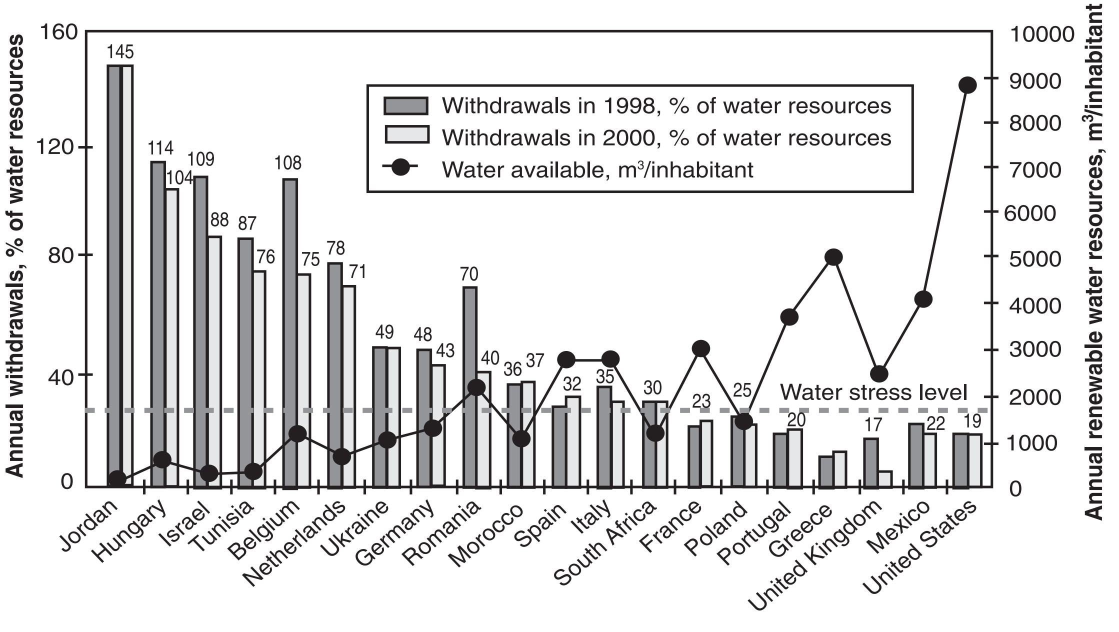
Another important criterion for evaluating water stress is water withdrawal as a percentage of the annual internal renewable water resources. Water management becomes a vital element in a country's economy when over 20 percent of the internal renewable resources are mobilized (Earth Trends, 2001). This is currently occurring in several European countries (**Figure 8-2a**) such as France, Spain, Italy, Germany, Ukraine, Belgium, the Netherlands, and Hungary. The Mediterranean region, North Africa, Morocco, Tunisia, Israel, and Jordan are facing high risks of water scarcity, meaning that in these areas, the major portion of the renewable resources are withdrawn. A number of arid and semi-arid countries meet water demands by seawater desalination or by withdrawals from non-renewable deep aquifers with extracted volumes 2 to 30 times higher than available renewable resources (**Figure 8-2b**).

Improving the efficiency of water use, water reclamation, and reducing distribution losses are the most affordable solutions to relieve water scarcity. For a number of countries in the Middle East and North Africa, where current fresh water reserves are, or will be, at the survival level, reclaimed wastewater is the only significant,

8-2a. **Countries with Chronic Water Stress Using Non-Renewable Resources**



8-2b. **Countries with Moderate Water Stress**



Source: Adapted by Lazarova, V. from Earth Trends 1999-2000, World Resource Institute low cost alternative resource for agricultural, industrial, and urban nonpotable purposes.

8.2.3 Environmental Protection and Public Health

In spite of the economic and ecological advantages associated with wastewater reuse, the key issue remains public health safety. The reuse of raw wastewater, still widely practiced in several regions in China, India, Morocco, Egypt, Pakistan, Nepal, Vietnam and most of South America, leads to enteric diseases, helminthic infections, and dangerous epidemics. In addition to public health risks, insufficiently treated effluent may also have detrimental effects on the environment. For example, high salinity levels in effluent can lead to a decrease in productivity for certain crops and destabilization of the soil structure. Another possible adverse effect is groundwater pollution. In the Mezquital Valley, north of Mexico City, 1,027 mgd (45 m^3/s, or 1.15 million acre-feet/year) of untreated wastewater from the capital city of Mexico City is used for agricultural irrigation in a 222,400-acre (90,000-hectare) area, year-round (IWA, 2002). This huge wastewater irrigation project, believed to be the largest in the world, has given rise to inadvertent and massive recharge of the local aquifers, and unintended indirect potable reuse of water from that aquifer by a population of 300,000 inhabitants.

8.3 Water Reuse Applications – Urban and Agriculture

Agriculture is the largest user of water, accounting for approximately 80 percent of the global demand. Consequently, agricultural irrigation is the major water reuse application worldwide. In a number of arid and semi-arid countries - Israel, Jordan, and Tunisia – water reuse provides the greatest share of irrigation water. Israel is the world's leader in this area, with over 70 percent of collected and treated wastewater reused for agricultural purposes (Kanarek and Michail, 1996).

Urban water reuse is developing rapidly, particularly in large cities, coastal, and tourist areas. Japan is the leader in urban water reuse, with 8 percent of the total reclaimed water (about 2,113 mgd or 8 millions m^3/year) used for urban purposes. The most common urban uses are for the irrigation of green areas (parks, golf courses, and sports fields), urban development (waterfalls, fountains, and lakes), road cleaning, car washing, and firefighting. Another major type of reuse is on-site water reuse within commercial and residential buildings. For example, Australia, Canada, Japan, and the United Kingdom use treated domestic wastewater for toilet flushing. Golf course irrigation is reported as the most rapidly growing application of urban water reuse in Europe (Lazarova, 1999), while replenishment of river flows for recreational uses is becoming increasingly popular in Spain and Japan.

There are several advantages to implementing urban reuse versus agricultural reuse:

- Most urban reuse, such as toilet flushing, vehicle washing, stack gas cleaning, and industrial processing is nonconsumptive; therefore, the water can be reused again for subsequent consumptive uses in agriculture or industry.

- The urban markets for water reuse are generally closer to the points of origin of the reclaimed water than are the agricultural markets.

- Urban reuse water generally holds a higher value than agricultural reuse because it can be metered and appropriate charges levied.

Wastewater treatment for reuse may have a lower cost than developing new water supply sources, particularly for low-quality reuse in toilet flushing and similar nonpotable urban uses. Agricultural irrigation will probably continue to dominate water reuse practices for many years into the future, especially in developing countries. However, reclamation projects are not likely to be built to serve agriculture. Over recent years, there has been increasing interest in indirect potable reuse in a number of industrialized countries (Australia, Belgium, France, Spain, South Africa, Singapore, and the U.S.) for water supply augmentation through the replenishment of surface reservoirs, aquifers, and salt intrusion barriers in coastal areas.

Untreated reuse water is a large and rapidly growing problem practiced in both low- and middle-income countries around the world. The International Water Management Institute (IWMI), based in Colombo, Sri Lanka, and the International Development Research Centre (IDRC), based in Ottawa, Canada held a workshop to discuss the use of untreated reuse water, at which a range of case studies were presented from Asia, Africa, the Middle East, and Latin America. At the workshop the Hyderabad Declaration on Wastewater Use in Agriculture was adopted.

The conference organizers are preparing an official, peer-reviewed publication based on this declaration. As previously mentioned, there are parts of the world where the wastewater management systems do not allow for the development of water reuse. In some regions untreated wastewater is improperly used for irrigation, usually illegally. The declaration recognizes that in situations where wastewater treatment to produce usable reuse water is not available, there are alternatives to improve the management of water reuse. The Hyderabad Declaration on Wastewater Use in Agriculture is reproduced below.

8.4 Planning Water Reuse Projects

Numerous state-of-the-art technologies enable wastewater to become a complementary and sustainable water

The Hyderabad Declaration on Wastewater Use in Agriculture

14 November 2002, Hyderabad, India

1. Rapid urbanization places immense pressure on the world's fragile and dwindling fresh water resources and over-burdened sanitation systems, leading to environmental degradation. We as water, health, environment, agriculture, and aquaculture researchers and practitioners from 27 international and national institutions, representing experiences in wastewater management from 18 countries, recognize that:

1.1 Wastewater (raw, diluted or treated) is a resource of increasing global importance, particularly in urban and peri-urban agriculture.
1.2 With proper management, wastewater use contributes significantly to sustaining livelihoods, food security and the quality of the environment.
1.3 Without proper management, wastewater use poses serious risks to human health and the environment

2. We declare that in order to enhance positive outcomes while minimizing the risks of wastewater use, there exist feasible and sound measures that need to be applied. These measures include:

2.1 Cost-effective and appropriate treatment suited to the end use of wastewater, supplemented by guidelines and their application
2.2 Where wastewater is insufficiently treated, until treatment becomes feasible:
  (a) Development and application of guidelines for untreated wastewater use that safeguard livelihoods, public health and the environment
  (b) Application of appropriate irrigation, agricultural, post-harvest, and public health practices that limit risks to farming communities, vendors and consumers
  (c) Education and awareness programs for all stakeholders, including the public at large, to disseminate these measures
2.3 Health, agriculture and environmental quality guidelines that are linked and implemented in a step-wise approach
2.4 Reduction of toxic contaminants in wastewater, at source and by improved management

3. We declare that:

3.1 Knowledge needs should be addressed through research to support the measures outlined above
3.2 Institutional coordination and integration together with increased financial allocations are required

4. Therefore, we strongly urge policy-makers and authorities in the fields of water, agriculture, aquaculture, health, environment and urban planning, as well as donors and the private sector to:

Safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation.

resource for a number of purposes in both developed and emerging countries, thus allowing utilities to reserve high quality and often scarce freshwater for domestic uses. The development and implementation of water reuse projects, however, remains difficult due to issues such as institutional discord, economics, funding, public health and environmental issues and, in some cases, a lack of public acceptance.

8.4.1 Water Supply and Sanitation Coverage

Despite increasing efforts to improve water supply and sanitation coverage in the world during the past 10 years, numerous regions and many large cities still do not have sufficient infrastructure (**Table 8-2**). According to a 2000 survey (Homsi, 2000), wastewater treatment coverage remains lower than water supply coverage and still represents an important constraint to implementing water reuse projects:

Sewage network coverage:

- Developed countries: 76 percent, except Japan, 54 percent and Portugal, 55 percent
- Developing countries: 35 percent, except Chile, greater than 90 percent

Wastewater treatment coverage:

- Developed countries: 75 percent, except Portugal, 36 percent
- Developing countries: greater than 10 percent

The situation becomes critical in a number of African and Asian countries, where water supply and sanitation coverage do not exceed 30 percent and 45 percent, respectively, including Afghanistan, Angola, Cambodia, Chad, Congo, Ethiopia, Haiti, Laos, Mauritania, and Rwanda. Despite these numbers, it is important to stress that more and more countries have effectively achieved total water supply and sanitation coverage, such as Andorra, Australia, Austria, Belarus, Bulgaria, Canada, Cyprus, Finland, South Korea, Lebanon, Netherlands, New Zealand, Norway, Singapore, Slovakia, Slovenia, Sweden, Switzerland, and the United Kingdom. Significant strides have also been made in a number of developing countries (**Figure 8-3a**) and it is expected that these figures will improve in several other countries with water resource problems (**Figure 8-3b**) due to governmental policies and increased investments.

8.4.2 Technical Issues

Treatment technology, another key aspect of the planning process, varies between planning a reuse project in an emerging country and planning a reuse system in a more industrialized country. In industrialized countries, where stringent control of water quality and operational reliability are the main requirements, modern, high cost technology may be more beneficial. In developing countries, relatively inexpensive labor and higher capital costs dictate that a facility, which can be built and operated with local labor, will be more cost effective than a facility utilizing more modern, capital-intensive technology.

Table 8-2. Wastewater Flows, Collection, and Treatment in Selected Countries in 1994 (Mm^3/Year)

Country	Generation Rate		Collection		Treatment		Treated, As Percent of Total	Treated, As Percent of Collected
	Mm^3/yr	MG/yr	Mm^3/yr	MG/yr	Mm^3/yr	MG/yr		
Cyprus	24	6,341	15	3,963	15	3,963	63%	100%
Egypt	1700	449,140	1138	300,660	950	250,990	55%	83%
Jordan	110	29,062	95	25,099	45	11,889	41%	47%
Morocco	500	132,100	400	105,680	170	44,914	34%	43%
Saudi Arabia	700	184,940	620	163,804	580	153,236	83%	94%
Syria	480	126,816	480	126,816	260	68,692	54%	54%
Tunisia	200	52,840	180	47,556	155	40,951	78%	86%
Turkey	2,000	528,400	1,700	449,140	1,100	290,620	55%	65%

Source: Table created from World Bank Working documents (UNDP, 1998)

Water Supply and Sanitation Coverage in Selected Countries

Figure 8-3a. **Countries with Total Water Supply and Sanitation Coverage over 80 Percent**

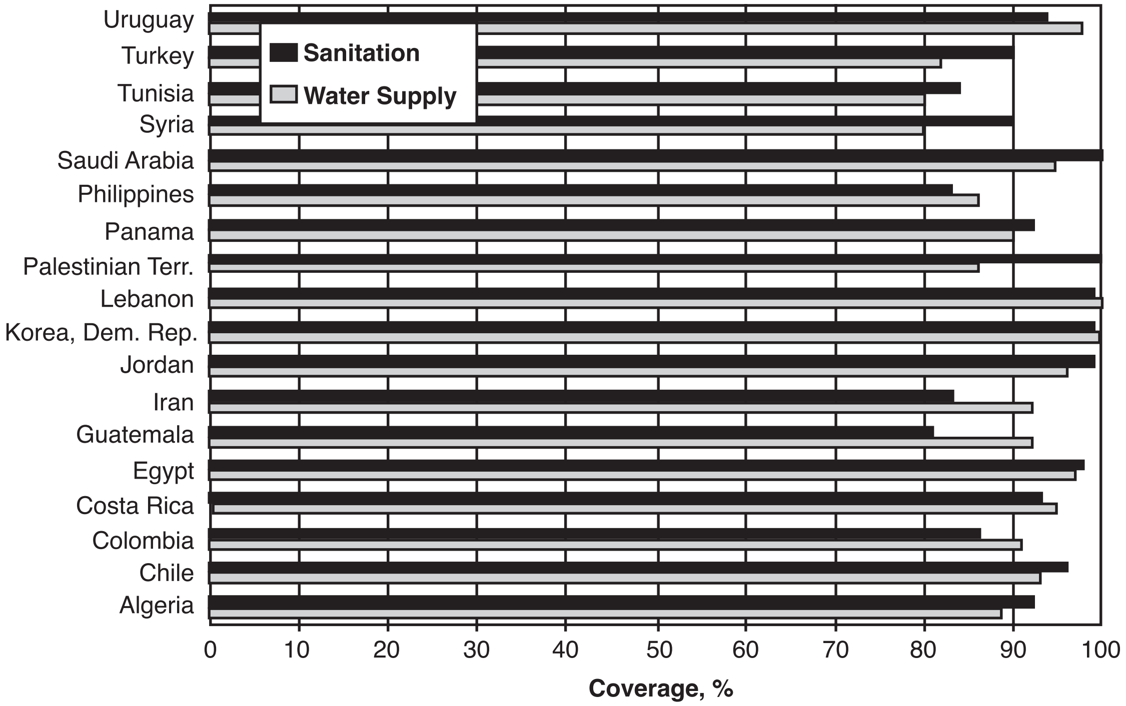
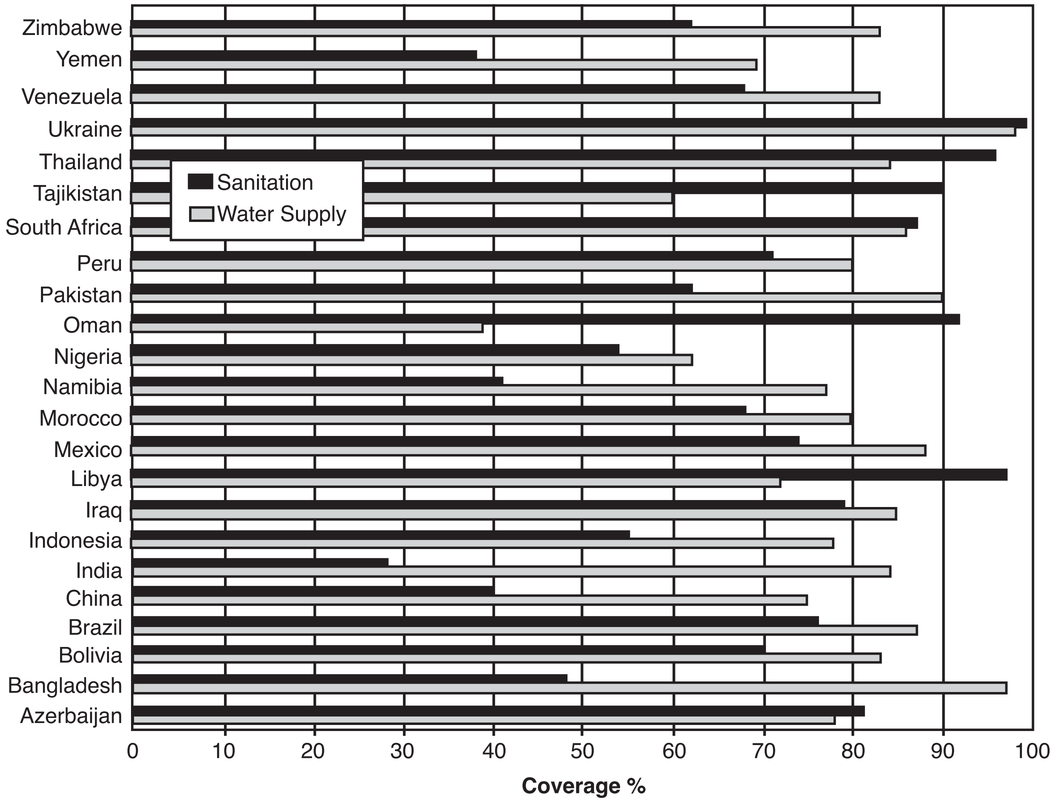


Figure 8-3b. **Countries with Total Water Supply and Sanitation Coverage Over 50 Percent**



Source: Figures for this table were assembled from WorldBank working documents (UNDP, 1998)

This section provides an overview of some of the technical issues associated with water reuse in developing countries that may differ from those presented in Chapter 2 for the U.S. Many of these issues result from the different technical solutions that are appropriate in a labor-intensive economy as compared with the capital-intensive economy of industrialized countries. Other differences result from dissimilarities in financial, material, and human resources, as well as in existing wastewater collection, treatment, and disposal facilities.

8.4.2.1 Water Quality Requirements

Water reuse standards or guidelines vary with the type of application, the regional context, and the overall risk perception. Depending on the project specifications, there will be different water quality requirements, treatment process requirements, and criteria for operation and reliability. However, the starting point for any water reuse project for any application is ensuring public health and safety. For this reason, microbiological parameters have received the most attention in water reuse regulations. Since monitoring for all pathogens is not realistic, specific indicator organisms are monitored to minimize health risks.

Table 8-3 provides a summary of water quality parameters of concern with respect to their significance in water reuse systems, as well as approximate ranges of each parameter in raw sewage and reclaimed water. The treatment of urban wastewater is typically designed to meet water quality objectives based on suspended solids (Total Suspended Solids (TSS) or turbidity), organic content (BOD), biological indicators (total or fecal coliforms, *E.coli*, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual. Additional water quality parameters for irrigation include salinity, sodium adsorption ratio, boron concentration, heavy metals content, and phytotoxic compounds content. The use of reclaimed municipal water for industrial purposes may require effluent limits for dissolved solids, ammonia, disinfection byproducts and other specific inorganic and organic constituents.

Different countries have developed different approaches to protecting public health and the environment, but the major factor in choosing a regulatory strategy is economics, specifically the cost of treatment and monitoring. Most developed countries have established conservatively low risk guidelines or standards based on a high technology/high-cost approach, such as the California standards. However, high standards and high-cost techniques do not always guarantee low risk because insufficient operational experience, OM&R costs, and regulatory control can have adverse effects. A number of developing countries advocate another strategy of controlling health risks by adopting a low technology/low-cost approach based on the WHO recommendations. A summary of select guidelines and mandatory criteria for reclaimed water use in a variety of U.S. states and other countries and regions is presented in **Table 8-4.**

Historically, water reuse standards are based on reuse for agricultural irrigation. The countries that have adopted the WHO recommendations as the basis for their agricultural reuse standards use both fecal coliforms (FC) and helminth eggs as pathogen indicators, respectively, at 1000 FC/100 ml and 1 helminth egg/l for unrestricted irrigation. The WHO recommends more stringent standards for the irrigation of public lawns than for the irrigation of crops eaten raw (fecal coliform count at 200 FC/100 ml, in addition to the helminth egg standard). Recent work, based on epidemiological and microbiological studies performed in Mexico and Indonesia support the WHO fecal coliform limit of less than 10^3 FC/100 ml, but recommends a stricter guideline value of less than 0.1 egg of intestinal nematode per liter (Blumenthal *et al.*, 2000). In the absence of recommendations for particulate matter, these standards use TSS at concentrations varying between 10 and 30 mg/l.

WHO recommends stabilization ponds or an equivalent technology to treat wastewater. The guidelines are based on the conclusion that the main health risks associated with reuse in developing countries are associated with helminthic diseases; therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture and aquaculture. The intestinal nematodes serve as indicator organisms for all of the large settleable pathogens. The guidelines indicate that other pathogens of interest apparently become non-viable in long-retention pond systems, implying that all helminth eggs and protozoan cysts will be removed to the same extent. The helminth egg guidelines are intended to provide a design standard, not an effluent testing standard.

The original 1973 WHO recommendations were more stringent than the 1989 recommendations. With respect to fecal coliforms, the standard rose from 100 FC/100 ml to 1000 FC/100 ml. The WHO guidelines are currently undergoing further revision. A draft guideline proposed by Bahri and Brissaud (2002) recommends massive revisions in the WHO guidelines, making them somewhat more restrictive, while maintaining the objective of affordability for developing countries. For example, in the draft guidelines, the helminth egg concentration limit is reduced from the current guideline of 1 egg/L to 0.1 egg/L for unrestricted irrigation. The proposed draft guidelines also cover various options for health protection,

Table 8-3. Summary of Water Quality Parameters of Concern for Water Reuse

Parameter	Significance for Water Reuse	Range in Secondary Effluents	Treatment Goal in Reclaimed Water
Suspended solids	Measures of particles. Can be related to microbial contamination. Can interfere with disinfection. Clogging of irrigation systems. Deposition.	5 mg/L - 50 mg/L	<5 mg SS/L - 30 mg SS/L
Turbidity		1 NTU - 30 NTU	<0.1 NTU - 30 NTU
BOD_5	Organic substrate for microbial growth. Can favor bacterial regrowth in distribution systems and microbial fouling.	10 mg/L - 30 mg/L	<10 mg BOD/L - 45 mg BOD/L
COD		50 mg/L -150 mg/L	<20 mg COD/L - 90 mg COD/L
TOC		5 mg/L - 20 mg/L	<1 mg C/L - 10 mg C/L
Total coliforms	Measure of risk of infection due to potential presence of pathogens. Can favor biofouling in cooling systems.	<10 cfu/100mL -10^7 cfu/100mL	<1 cfu/100mL - 200 cfu/100mL
Fecal coliforms		<1-10^6 cfu/100mL	<1 cfu/100mL - 10^3 cfu/100mL
Helminth eggs		<1/L - 10/L	<0.1/L - 5/L
Viruses		<1/L - 100/L	<1/50L
Heavy metals	Specific elements (Cd, Ni, Hg, Zn, etc) are toxic to plants and maximum concentration limits exist for irrigation	---	<0.001 mg Hg/L <0.01 mg Cd/L <0.1 mg Ni/L - 0.02 mg Ni/L
Inorganics	High salinity and boron (>1mg/L) are harmful for irrigation	---	>450 mg TDS/L
Chlorine residual	To prevent bacterial regrowth. Excessive amount of free chlorine (>0.05) can damage some sensitive crops	---	0.5 mg Cl/L - >1 mg Cl/L
Nitrogen	Fertilizer for irrigation. Can contribute to algal growth, corrosion (N-NH4) and scale formation (P).	10 mg N/L - 30 mg N/L	<1 mg N - 30mgN/L
Phosphorus		0.1 mg P/L - 30 mg P/L	<1 mg P/L - 20 mg P/L

Source: Adapted from Lazarova, 2001; Metcalf and Eddy, 1991; Pettygrove and Asano, 1985

such as treatment of wastewater, crop restrictions, application controls, and control of human exposure. The multi-barrier approach throughout the water cycle is also considered an important element. WHO wastewater reuse initiatives are considering 4 categories of reuse: (a) agriculture, (b) aquaculture (shellfisheries), (c) artificial recharge exclusively for potable supply, and (d) urban use.

The premise is that better health protection can be achieved by not only implementing stringent water quality limits but also by defining other appropriate practices that could provide additional barriers for pathogens depending on the type of reuse. Such an approach has been proposed in the new Israeli standards (Shelef and Halperin, 2002). In 1999, new standards were issued by the Israeli Ministry of Health (Palestine Hydrology Group, 1999), defining 5 qualities of reclaimed water, as follows:

1. Effluents of very high quality, suitable for unrestricted irrigation—no barriers required

2. Effluents of high quality—2 barriers required for irrigation

3. Oxidation pond effluents—2 to 3 barriers required for irrigation

4. Effluents of medium quality—3 barriers required for irrigation

5. Effluents of low quality—only specific “no-barrier” crops are allowed to be irrigated

These standards set a low coliform limit of less than 10 *E. coli*/100 ml for very high quality reclaimed water that does not require additional barriers (the first quality listed

Table 8-4. Summary of Water Recycling Guidelines and Mandatory Standards in the United States and Other Countries

Country/Region	Fecal Coliforms (CFU/100ml)	Total coliforms (cfu/100 ml)	Helminth eggs (#/L)	BOD_5 (ppm)	Turbidity (NTU)	TSS (ppm)	DO (%of Sat)	pH	Chlorine residual (ppm)
Australia (New South Wales)	<1	<2/50	--	>20	<2	--	--	--	--
Arizona	<1	--	--	--	1	--	--	4.5-9	--
California	--	2.2	--	--	2	--	--	--	--
Cyprus	50	--	--	10	--	10	--	--	--
EC bathing water	100 (g)	500 (g)	--	--	2 (g)	--	80-120	6-9	--
	2,000 (m)	10,000 (m)			1 (m)				
France	<1000	--	<1	--	--	--	--	--	--
Florida (m)	25 for any sample for 75%	--	--	20	--	5	--	--	1
Germany (g)	100(g)	500 (g)	--	20 (g)	1-2 (m)	30	80-120	6-9	--
Japan (m)	10	10	--	10	5	--	--	6-9	--
Israel	--	2.2 (50%) 12(80%)	--	15	--	15	0.5	--	0.5
Italy	--	--	--	--	--	--	--	--	--
Kuwait Crops not eaten raw	--	10,000	--	10	--	10	--	--	1
Kuwait Crops eaten raw		100		10		10			1
Oman 11A	<200	--	--	15	--	15	--	6-9	--
Oman 11B	<1000			20		30		6-9	
South Africa	0 (g)	--	--	--	--	--	--	--	--
Spain (Canary islands)	--	2.2	--	10	2	3	--	6.5-8.4	1
Texas (m)	75(m)	--	--	5	3	--	--	--	--
Tunisia	--	--	<1	30		30	7	6.5-8.5	--
UAE	--	<100	--	<10	--	<10	--	--	--
United Kingdom Bathing Water Criteria	100 (g)	500 (g)	--	--	2 (g)	--	80-120	6-9	--
	2000 (m)	10000 (m)			1 (m)				
US EPA (g)	14 for any sample, 0 for 90 %	--	--	10	2	--	--	6-9	1
WHO (lawn irrigation)	200 (g)	--	--	--	--	--	--	--	--
	1000 (m)								

Note: (g) signifies that the standard is a guideline and (m) signifies that the standard is a mandatory regulation
Source: Adapted from Cranfield University, 2001. Urban Water Recycling Information Pack, UK

above) and can be used for irrigation of vegetables eaten raw. Additional barriers are identified as:

- Physical barriers, such as: buffer zones, plastic groundcovers and underground drip irrigation
- Crops or fruits that are normally treated under high temperature and/or are eaten only cooked (e.g., wheat), as well as those with an inedible peel or shell (e.g., citrus, banana, nuts)

No-barrier crops are defined in the following categories: (1) industrial crops (such as cotton or fodder); (2) crops whose harvestable parts are dried in the sun for at least 60 days after the last irrigation (including sunflower, wheat, chickpeas intended for cooking); (3) watermelon for edible seeds or for seeds that are irrigated before flowering; (4) woody crops or plants with no public contact; and, (5) grass for sale with no public access to the plot.

The government of Tasmania, Australia, issued the tenth draft of its, "*Environmental Guidelines for the Use of Recycled Water in Tasmania*" (Tasmanian website). These guidelines are intended to provide a framework to allow sustainable water reuse in a manner that is practical and safe for agriculture, the environment, and the public while also remaining consistent with industry standards and best environmental practice management (Dettrick and Gallagher, 2002). Issues of soil sustainability, including permeability hazard, salinity hazard, groundwater protection, and crop health, are discussed in the guidelines. A comprehensive health risk management framework is provided that gives different levels of risk management for 3 quality classes of wastewater including: backflow prevention, public access and withholding, safety for workers dealing with reclaimed water, food safety issues, and grazing animal withholding. The Tasmanian guidelines identify 3 categories of reclaimed water:

- Class A **Recycled** Water: No restriction on public access less than 10 cfu /100 ml

- Class B **Reclaimed** Water: Limited restrictions apply less than 100 cfu /100 ml or less than 1,000 cfu/100 ml depending upon type of application

- Class C **Treated** Water: Access restricted less than 10,000 cfu/100 ml

No potable reuse or body contact with reclaimed water is addressed in the Tasmanian guidelines because of the high level and cost of treatment necessary to produce the requisite quality reclaimed water. Irrigation of treated wastewater to riverside land less than 6 miles (10 kilometers) upstream of a town water supply intake is generally not permitted.

8.4.2.2 Treatment Requirements

Wastewater treatment is the most effective way to reduce the health, environmental, and other risks associated with the use of reclaimed water. Choosing the most appropriate treatment technology for water reuse is a complex procedure that must take into consideration various criteria, including technical and regulatory requirements, as well as social, political, and economic considerations specific to the local conditions. It is important to stress that economic and financial constraints have to be taken into account in countries where reclaimed water is a vital water resource for sustainable development.

Depending on water quality objectives, plant capacity, land availability, and climate conditions, extensive low-tech technologies, also known as non-conventional processes, can be used in water reuse facilities. Wastewater treatment processes, such as stabilization ponds or lagooning, infiltration-percolation, soil-aquifer treatment, and wetlands, are well adapted to the climate conditions in tropical and subtropical zones. Their relatively low OM&R costs and easy upkeep are important advantages for developing countries. However, these treatment technologies require large land availability, are associated with high evaporation losses resulting in high salinity concentrations, and are recommended predominantly for small treatment units, with less than 5000 population equivalents (700 m^3/d or 0.2 mgd) (Lazarova *et al.,* 2001).

Over the last decade, an increased number of studies conducted in different countries have shown that stabilization pond systems in series can produce effluent with microbiological water quality suitable for unrestricted irrigation (WHO guidelines category A, less than 1000 FC/100 ml and less than 1 helminth egg/L) (Lazarova, 1999). The hydraulic residence time varies in the range of 20 to 90 days according to the climate conditions and the optimal lagoon depth is 1.2 to 1.5 meters. Under optimal operating conditions, the disinfection efficiency is 3 to 5 log removal, with maximum values up to 5 to 6 log removal for fecal coliforms. A removal rate of 5 to 6 log of fecal coliforms in stabilization ponds can only be achieved if maturation ponds are provided. Stabilization ponds operating in Brazil have been shown to provide a 3-log removal of intestinal nematodes (Mara and Silva, 1986).

One of the drawbacks of using a stabilization pond system is the restricted operation flexibility, especially during flow and seasonal variations. Activated sludge treatment used in conjunction with tertiary treatment ponds has proven to be a reliable and efficient method for disinfection with the elimination of fecal coliform, viruses, and helminth eggs. The ponds also provide the required storage capacity for irrigation. High evaporation rates, particularly in dry and windy zones, are the major disadvantage of this treatment technology.

The increased use of constructed wetlands in developing countries has been slow, despite favorable climate conditions. Adequate wetlands systems designs for tropical and subtropical zones have not yet been developed. Several field studies performed in constructed wetlands for secondary treatment show that the pathogen reduction (2 to 3 log reduction of fecal coliforms and coliphages) is not sufficient to satisfy the WHO water quality guidelines for irrigation.

Larger cities with existing sewage systems are the most promising locations for implementing water reuse. Conventional treatment is likely to be the treatment of choice because of limited land availability, the high cost of land, the considerable transmission distance to reach the treatment site, and lack of public acceptability, particularly as city growth nears the vicinity of the treatment sites.

With the increased concern for public health, choosing a disinfection technology is recognized as one of the critical steps in developing a water reclamation system. The treatment quality upstream of disinfection has a great impact on the doses required for a given disinfection level. Therefore, if a stringent regulation must be met, disinfection alone cannot make up for inefficient upstream treatment and often must be coupled with tertiary filtration or other advanced treatment processes. The growing use of ultraviolet (UV) technologies for disinfection in wastewater reuse plants worldwide is largely attributed to low costs, as well as the absence of toxic byproducts. One drawback to using UV disinfection in reuse systems is the lack of disinfection residual, which is mandatory in distribution tanks, holding tanks, and reservoirs.

In addition to appropriate treatment technology, adequate monitoring is also important. Although not always feasible in developing countries, on-line, real-time monitoring is preferable to sampling and laboratory analysis where the results arrive too late to take corrective action. A simple and useful measurement of water quality for reclaimed water is turbidity. Experience can relate turbidity to other parameters of interest but, more importantly, a sudden increase in turbidity beyond the operating standard provides a warning that corrective action is required. For example, practice in the U.S. often requires that, should the turbidity exceed 2 NTU for more than 10 minutes, the reclaimed water be diverted to storage to be retreated.

Treatment cost is an extremely important consideration everywhere, but especially where financial resources are very limited. A recent analysis by Lazarova (2001) summarized the unit costs of various treatment levels for a 40,000 population-equivalent size treatment plant. The results are shown in **Table 8-5**. The treatment costs for producing reclaimed water are highly influenced by local constraints, such as the price of the building site, distance between the production site and the consumers, and whether or not there is a need to install a dual distribution system or retrofit an existing system.

8.4.3 Institutional Issues

Planned water reuse is best accomplished through the collaboration of at least 2—and often more—institutions. Without collaboration, only unplanned or incidental water reuse might occur. The institutions with a stake in water reuse include those responsible for water supply, wastewater management, water resources management, environmental protection, and public health and, in many cases, agriculture. Furthermore, these agencies may have responsibilities at local, regional and national levels. More often than not, there is a wide chasm between these agencies. Acknowledging that the ideal situation rarely exists, and that there is an institutional barrier to developing a new water reuse initiative, overcoming barriers and forgoing the necessary links among agencies should be the first step in any planning effort. An administrative reorganization may be necessary to guarantee the development of water reuse into a general water management group. Examples of such changes include those taking place in developing countries like Tunisia, Morocco, and Egypt. Ideally, it would be most desirable to have just one agency in charge of the entire water cycle in a given hydrologic basin.

A critically important “partner” in a safe and successful water reuse program is the independent regulatory agency with oversight and enforcement responsibility over all the partners involved in water reuse. It would be a conflict of interest for either the water supplier or the wastewater manager to have this regulatory role; therefore, the most logical “home” for the regulatory function is with the agency charged with protection of public health and/or the environment.

8.4.4 Legal Issues

There are 2 basic types of legal issues relevant to water reuse: (1) water rights and water allocation; and (2) the protection of public health and environmental quality. Other legal issues may also be relevant in specific circumstances.

8.4.4.1 Water Rights and Water Allocation

Diverting existing wastewater flows to a treatment facility will, at a minimum, change the point at which the flow is discharged to surface waters, and may change the amount of water available to current users further downstream. A water reuse project may completely deprive existing users of their current supply if reclaimed water is sold to new users (e.g., industrial facilities) or allocated to new uses (e.g., municipal use).

Traditional practice and customary law in most developing countries recognizes that a water user acquires vested rights. Changing the amount of water that is available to a current user may entitle the user to some type of remedy, including monetary compensation or a supplemental water supply. A proposed water reuse project needs

Table 8-5. Life-Cycle Cost of Typical Treatment Systems for a 40,000 Population- Equivalent Flow of Wastewater

Treatment System	Unit Cost[1]		
	per m^3	per AF	per MG
Stabilization Ponds (Land Cost not Included)	\$0.18	\$222.00	\$0.68
Activated Sludge (Secondary)	\$0.34	\$420.00	\$1.29
Activated Sludge + Filtration + UV Irradiation	\$0.42	\$518.00	\$1.59
Additional Cost of Full Tertiary Treatment (Title 22)	\$0.24	\$296.00	\$0.91
Additional Cost of Disinfection	\$0.07	\$86.00	\$0.26
Lime Pretreatment + Reverse Osmosis (After secondary treatment)	\$0.75	\$926.00	\$2.84
Microfiltration + Reverse Osmosis (After secondary treatment)	\$0.54	\$667.00	\$2.04

[1] Cost in U.S. Dollars
Adapted from Lazarova, 2001

to consider the impact on current patterns of water use and determine what remedies, if any, are available to or should be created for current users if the project interferes with their water uses.

8.4.4.2 Public Health and Environmental Protection

The use of reclaimed water for agricultural irrigation and various municipal uses may result in human exposure to pathogens or chemicals, creating potential public health problems. Water reclamation and reuse, and the disposal of sludge from wastewater treatment, may also have adverse effects on environmental quality if not managed properly.

Planning for water reuse projects should include the development and implementation of regulations that will prevent or mitigate public health and environmental problems. Such regulations include:

- A permit system for authorizing wastewater discharges
- Water quality standards for reclaimed water that are appropriate for various uses
- Water quality standards for river discharge when water reuse is seasonal, intermittent, or less than the effluent rate of the wastewater treatment facility
- Controls that will reduce human exposure, such as restrictions on the uses of reclaimed water
- Controls on access to the wastewater collection system and controls to prevent cross-connections between the distribution networks for drinking water and reclaimed water
- Regulations concerning sludge disposal and facility location
- Mechanisms for enforcing all of the above regulations, including monitoring requirements, authority to conduct inspections, and authority to assess penalties for violations

A number of other legal issues discussed in Chapter 5 are also relevant to developing countries.

8.4.5 Economic and Financial Issues

The economic justification for water reuse depends principally on either offsetting the costs of developing additional water sources or on reducing the overall wastewater treatment costs. The full cost of developing and managing the water supply, wastewater management system, and water reuse system needs to be understood in order to conduct a rigorous economic analysis.

The economic rationale for water reuse outside of the U.S. does not differ much from that set out in Chapter 6. Benefits associated with water reuse include savings from not having to develop new water sources, reduced treatment requirements, and the economic value of the reclaimed water.

The enterprises responsible for water supply services in developing countries function with varying degrees of success, but increasingly, the utility companies recover their operating costs through user fees. User fees and/or public funds also have to fund the wastewater treatment system, if provided by the same institution.

8.5 Examples of Water Reuse Programs Outside the U.S.

Based on a review of water reuse projects outside the U.S., it can be concluded that the number of countries investigating and implementing water reuse has increased over the past decade. Hence, water reuse is growing steadily not only in water-deficient areas (Mediterranean region, Middle East, Latin America), but also in highly populated countries in temperate regions (Japan, Australia, Canada, North China, Belgium, England, Germany). The suitability of water reuse, especially in arid and semi-arid regions, is now nearly universally recognized. However, the societal ability and willingness to make the necessary investment for infrastructure improvement depends on local circumstances and varies considerably from country to country.

The principal reuse application remains agricultural irrigation, especially in developing countries. Urban, nonpotable reuse, such as reuse for, landscape irrigation, road cleaning, car washing, toilet flushing, and river flow augmentation, is developing rapidly in high density urban and tourist areas. Indirect potable reuse and the use of reclaimed water for industrial purposes have also been receiving increased attention in several industrialized countries. The only existing example of direct potable water reuse remains the Windhoek plant in Namibia. There have not been any adverse public health impacts reported during the 34 years of the plant's successful operation.

This section illustrates the applications of water reuse in several industrialized countries as well as several developing countries where an interest in reuse is just beginning. This inventory is intended to be illustrative rather than exhaustive. For the convenience of the reader, the case studies have been listed in alphabetical order.

8.5.1 Argentina

Argentina is characterized by various climatic zones: tropical, humid climate in the northeastern region with large rivers such as the Parana and Uruguay; mild and humid climate in the central flat region of the pampas with few sources of surface water; and arid and semi-arid regions in the west and south. Only 35 percent of the population is connected to sewer systems and only part of the collected sewage undergoes appropriate treatment (Pujol and Carnabucci, 2000). Large-scale reuse of untreated wastewater has been occurring since the beginning of the 20th century in densely populated areas in the western regions of the country for the purpose of agricultural irrigation. Argentina requires that water reuse practices must be in compliance with the WHO standards, but in some regions, raw wastewater or minimally treated effluent are still being used for irrigation (Kotlik, 1998). In the large cities, there are plans to use trickling filters and activated sludge systems. In the arid areas, conventional stabilization ponds are used for treatment for agricultural reuse.

Driven by water scarcity, the largest water reuse system in Argentina is located in the arid region of Mendoza, in the western part of the country near the Andes. Over 160,000 m^3/d (42.3 mgd) of urban wastewater (1 million inhabitants, 100 Mm^3/year or 26,400 mg/year) is treated by one of the largest lagooning systems in the world at the Campo Espejo wastewater treatment plant with a total area of 290 hectares (643 acres) to meet the WHO standards for unrestricted irrigation by means of facultative stabilization ponds (Kotlik, 1998). Reuse water in this region is a vital water resource, enabling the irrigation of over 3,640 hectares (8,995 acres) of forests, vineyards, olives, alfalfa, fruit trees and other crops. Improved water reuse practices are under development to avoid contamination of aquifers, including establishment of special areas for restricted crops and restrictions in the choice of irrigation technologies. An extension of this water reuse system is planned in the northern region of the Mendoza City Basin, where the treated effluent from the Paramillo wastewater treatment plant (100,000 m^3/d or 26.4 mgd, series of stabilization ponds) is diluted with the flow from the Mendoza River and used for irrigation of a 20,000-hectare (49,420-acre) oasis.

8.5.2 Australia

8.5.2.1 Aurora, Australia

Aurora is a proposed new 650-hectare development to be located in the outer northern suburbs of Melbourne, Australia. The development is intended to showcase sustainable development principles. A key feature will be water conservation, with a plan to utilize recycled treated wastewater for nonpotable use. The work undertaken so far indicates that with water reuse and demand management combined, there is the potential to reduce the demand on the potable reticulated system in the order of 70 percent. Construction was planned to commence in 2003, with an estimated 15 years before full development, at which stage, around 9,000 dwellings will exist, housing a population of 25,000.

Reuse systems completed to date convey wastewater to a decentralized treatment plant and distribute it via a separate, metered pipe system back to each dwelling. At present, Melbourne's typical separate water systems include potable water supply, wastewater collection, and storm water collection. The recycled pipes will therefore represent a fourth system that will be plumbed for irrigation and toilet flushing.

Wastewater will need to be treated to Class A standards to meet the state's Environmental Protection Agency and Department of Health requirements for the intended use. Class A standards require treated effluent to achieve the following standards:

- 10 *E.coli* per 100 ml
- 1 helminth per liter
- 1 protozoa per 50 liters
- 1 virus per 50 liters

It is envisioned that the project will utilize surface storage; however, aquifer recharge and recovery is being investigated as another mechanism for water balancing. Despite these 2 potential methods, it is anticipated that there will be continual need for the facility to discharge treated effluent into the local waterway during times of high rainfall. An environmental impact study is being conducted for both the groundwater and stream to determine adequate water quality standards for discharge to occur. At this stage, it appears that discharge targets for the stream releases will need to meet Class A standards, as well as to keep phosphorus and nitrogen below 0.1 mg/L and 1 mg/L, respectively.

8.5.2.2 Mawson Lakes, Australia

Mawson Lakes will be an innovative urban development 12 kilometers (7.5 miles) north of Adelaide, designed to integrate evolutionary strategies into economic, social, and environmental activities. The development is designed for 8,000 to 9,000 residents in 3,200 dwellings, and includes a town center and commercial properties.

A key component of the development is to create a reclaimed water supply system that will reduce household potable demand by at least 50 percent by providing reclaimed storm water and wastewater for outdoor, domestic, and municipal irrigation. Stormwater run-off from roofs, paths, roads, and the general area, as well as treated wastewater will be collected and treated, and then stored in groundwater aquifers for reuse. Houses have both a potable water main connection and a reclaimed water connection. The reclaimed water will be used for toilet flushing, garden irrigation, and car washing. Public open space will also be irrigated with reclaimed water.

Stormwater is to be harvested from the 620-hectare (1,532-acre) development site plus an equivalent area of adjoining industrial land. An established wetland adjacent to the development will augment the proposed system and provide additional storage for the harvested stormwater. Prior to entering the wetland system, the stormwater will be screened through a combination of gross pollution traps and wetland basins.

8.5.2.3 Virginia Project, South Australia

The Virginia pipeline project was built to transport over 20,000 megaliters (5,284 million gallons) of reclaimed water (approximately 20 percent of the wastewater produced in the Adelaide area) from the Bolivar Treatment Plant just north of Adelaide to the Virginia area. The secondary effluent from the treatment plant receives further treatment after transmission in a Dissolved Air Flotation Filtration (DAFF) system which improves the water quality to less than 10 *E. Coli*/ 100 ml – the Australian standard for irrigation for crops eaten raw. The reclaimed water system serves over 220 irrigators in the Virginia area - the majority of the customers are horticultural farmers who produce root and salad crops, brassicas, wine grapes, and olives.

The project was developed in response to 3 problems: nutrients in the secondary effluent were damaging an environmentally sensitive gulf, irrigators were experiencing declining yields, and there was an increase in salinity in underground aquifers. The reduced water resource was expected to cause reduced production and employment in an area which already faced high unemployment. Even though there were 3 drivers for a reclaimed water system, the project remained in the planning stages until 4 major issues were overcome: (1) project financing; (2) a public-private partnership; (3) water quality standards; and, (4) marketing. Multiple stakeholders including government, the water authority, regulatory authorities, potential customers, and the project developer further complicated the project; however, the common goal to see the project proceed overcame the individual interests of each party.

The project has been operating since 2000 and the owners are considering extending the system to meet demand that was unable to be met in the original development. There have been no public health concerns and

Table 8-6. Summary of Australian Reuse Projects

Project	Annual Volume		Water Quality[1]	Application	Comment
	(ML)	(MG)			
Virginia	22,000	5,815	A	Unrestricted irrigation of horticultural crops including salad crops	Built to overcome problems from nutrient discharges and declining aquifer. Largest operating reuse project in Australia – completed in 2000.
South East Queensland	100,000+	26,420	A and C	Class A water similar to Virgina project in major horticultural region. Class C to cotton and cereal farms.	Major engineering, financial, economic, and social impact study recently completed estimating using all of Brisbane's wastewater – however, smaller project more likely to proceed.
Hunter Water	Up to 3,000	Up to 795	C and B	Coal washing and electricity generator cooling.	Operating in a location where labor relations are typically difficult.
Eastern Irrigation Scheme	10,000	2,645	C	Stage 1 - horticulture , public spaces, and golf courses. Stage 2 - distribution to homes for household gardens and toilet flushing.	Stage 1 water sold and project is under construction.
Barwon Water Sewer Mining	Up to 1,000	Up to 265		Agricultural and industrial uses.	Feasibility study only.
McClaren Vale	Up to 8,000	Up to 2,115	Class C	Application to vines for producing premium quality wine grapes.	System in operation. Annualized water price exceeds that for potable water.
Rouse Hill	Up to 1,500	Up to 400	Class A	Reclaimed water distributed to 15,000 households using a dual distribution system. Future plans to serve a total of 35,000 households.	System in operation.
Georges River Program	15,000 to 30,000	3,960 to 7,925	Varying standards based on application	50 kilometers (31 miles) Reclaimed water pipeline to serve existing potable water customers and new residential developments	Environmental Impact Statement completed and projected is to begin construction in 2004.
Other projects	---	---	All Class B or Class A	Applications include wine grapes, sugar, pasture and fodder, including that for dairy cattle, water cooling for an oil refinery, golf course and recreational area watering, tree lots, and dust suppression.	While exact numbers are not known there is likely to be more than 50 schemes and individual applications in Australia. Most state governments and water authorities have policies on reuse and devote efforts to developing new applications.

[1] Class A Water = less than 10 *E. Coli*/100 ml
Class B Water = less than 100 *E. Coli*/100 ml
Class C Water = less than 1,000 *E. Coli*/100 ml

there is continuous monitoring for environmental impacts such as accession of irrigation water to the water table and build-up of salts in the soil profile. **Table 8-6** gives a summary of this project and other reuse projects in Australia.

8.5.3 Belgium

Belgium has one of the lowest water availabilities among the countries of the European Union (EU) with 2000 m^3/capita/year (528,300 gallons/capita/year). Only 45 percent of the sewage is currently treated, with plans to treat almost all wastewater by 2006. The amount of wastewater reuse remains limited; nevertheless, using reclaimed water is becoming increasingly attractive to industries such as power plants and food processing plants. Other industries with high rates of water utilization or industries located in areas of dropping water tables or high summer water demand are also moving more towards water reuse. The elimination of wastewater discharge in environmentally sensitive areas is another incentive for developing water reuse projects.

There is one indirect potable reuse project that has proven to be a cost-effective and environmentally beneficial solution. The system not only provides additional water, but also provides a saltwater intrusion barrier. At the Wulpen wastewater treatment plant, up to 2.5 Mm^3/year (660 mg/year) of urban effluent is treated by microfiltration (MF) and reverse-osmosis (RO), stored for 1 to 2 months in an aquifer, and then used for water supply augmentation.

There was another attempt to reuse 10,000 to 24,000 m^3/d (2.6 to 6.3 mgd) of wastewater to recharge an aquifer in Heist; however, infiltration could not be achieved through the soil due to low hydraulic conductivity. The only other option was to do direct reuse. In the end, the project team decided to use surface water as the raw water source.

A third possible water reuse project is still under study. It involves the treatment of about 8,000 m^3/d (2.1 mgd) of effluent from the Waregem wastewater treatment plant for direct reuse in the neighboring textile industry. The technical feasibility study has shown that the required effluent quality can be obtained through the use of a combined process of sand filtration, MF, and RO*.*

8.5.4 Brazil

Brazil is one of the countries with the most abundant water resources (8 percent of the world's fresh water, equivalent to about 40,000 m^3/capita/year or 10.5 mg/capita/year in 2000). In spite of this, 80 percent of the fresh water in Brazil is in the Amazon basin in the northern region of the country, leaving 20 percent bounded to the area that concentrates about 65 percent of the population (southeastern, southern, and central-western Brazil) as seen in **Table 8-7**. Despite having a great potential of water, water conflicts occur in some areas of the country. For example, the Upper Tietê River Basin has about 18 million inhabitants and is one of the world's largest industrial complex, yet the region only has a specific water availability of only 179 m^3/capita/year (47,290 mg/capita/year). On the other hand, irrigation is growing steadily in the country, reaching a consumptive use of about 69 percent at national level.

The Law nº 9,433 of January, 1997, established the National Water Resources Policy and created the National Water Resources Management System. Since then, the country has had a legal instrument to ensure future generations the availability of water in adequate conditions. In July, 2000, the Law nº 9,984 created the National Water Agency, linked to the Ministry of the Environment, but with administrative and financial autonomy. Among several other attributions, the Agency will supervise, control, and evaluate the actions and activities resulting from compliance with the federal legislation; grant, by means of licensing, the right to use water resources in bodies of water that are in the Union domain; encourage and support initiatives to institute River Basin Committees; and collect, distribute, and apply revenues obtained by billing for the use of water resources in the Union domain, etc.

In a country with a population of 173 million in 2001, a full 60 percent of the population was not connected to sewer systems. Only 34 percent of the wastewater flow collected that was collected was treated in 1996. The situation has a clearly visible negative impact on the environmental quality of many of Brazil's urban river basins and public health. However, it is important to underline that Brazil achieved substantial progress with regard to the coverage of water supply and sanitation services over the past 3 decades, much of this effort being the fruit of the Government's National Water and Sanitation Program. In urban areas, access to potable water supplies rose from 50 percent in 1968 to 91 percent in 1997. Sewage coverage increased from 35 percent to 43 percent in the same period. The sewage coverage in urban areas was significantly improved to 85 percent in 2000.

There are a great deal of wastewater reuse planning and actions being implemented in Brazil. Most of them are associated with industrial projects: resource recovery, demand management, and minimization of effluent discharge. Municipalities recognize the benefits of nonpotable urban reuse and have started to make plans to optimize the use of local water resources. On the other hand, unplanned (and sometimes unconscious) agricultural reuse is performed in many parts of the country, particularly for the irrigation of fodder crops and vegetables. Water is diverted from heavily polluted sources to be applied to crops without treatment or adequate agronomic measures. It is expected that the new regulations to be placed into law by the Agency will regulate the practice nationwide, promoting at the same time, the implementation of public health and environmental safeguards to new projects.

8.5.4.1 São Paulo, Brazil

Metropolitan São Paulo, a city with 18 million people and a very large industrial complex, is located in a plateau in the heads of the Tietê River. A small amount of local water availability has forced the region to survive on the importation of water resources from neighboring basins. Two sources of water have been considered for reuse: municipal wastewater (which contains a significant amount of industrial effluents) and the volumes retained in flood control reservoirs. The available volumes for reuse and the corresponding quality of the treated effluents are shown in **Table 8-8**.

Three potential types of water reuse applications have been identified.

- **Industrial use**, for cooling towers, boiler feed water, process water in metallurgic and mechanical industries, floor washing, and irrigation of green spaces

Table 8-7. Water Demand and Water Availability per Region in the Year 2000

Region	Inhabitants	Specific Water Demand (m^3/capita/yr)	Specific Water Demand (gal/capita/yr)	Specific Water Availability (m^3/capita/yr)	Specific Water Availability (mg/capita/yr)	Demand (% of Available)
North	12,900,704	204	53,890	513,102	135.5	0.04%
Northeast	47,741,711	302	79,780	4,009	1.1	7.53%
Southeast	72,412,411	436	115,180	4,868	1.3	8.96%
South	25,107,616	716	189,150	15,907	4.2	4.50%
Central West	11,636,728	355	93,780	69,477	18.4	0.51%
Brazil	169,799.17	414	109,370	40,000	10.6	1.03%

Table 8-8. Effluent Flow Rate from Wastewater Treatment Plants in Metropolitan Sao Paulo

WWTP	Design Flow		Treated Flow [a]	
	(Mm^3/day)	(mgd)	(Mm^3/day)	(mgd)
ABC	0.26	68.47	0.13	35.38
Barueri	0.82	216.83	0.57	151.78
Parque Novo Mundo	0.22	57.06	0.13	33.32
São Miguel	0.13	34.24	0.05	13.69
Suzano	0.13	34.24	0.07	18.94
Total Flow	1.6	410.84	0.96	253.12

[a] data from operational data, March 2002

- **Restricted urban use**, for toilet and urinal flushing, vehicle, floor and street washing, decorative water features such as fountains, reflecting pools and waterfalls, cleaning sewer and flood galleries, preparation of concrete and soil compaction, irrigation of sports fields, parks, and gardens

- **Unrestricted urban use,** for irrigation of green areas where public access is restricted, as well as, irrigation of industrial and fodder crops and pastures.

8.5.4.2 São Paulo International Airport, Brazil

The São Paulo International Airport of Guarulhos has 2 terminals, each one handling about 7 million passengers per year. Terminal 3 will serve an additional 16 million passengers per year, to reach the saturation level of about 30 million passengers per year by 2030. An additional water demand, in the order of 3,000 m^3/d (792,500 gallons/d) will produce a total wastewater flow of 6,400 m^3/d (1.7 mgd). Groundwater is the sole source of water, and due to excessive pumping, the aquifer is recessing, increasing the potential for ground subsidence. A wastewater reuse project is in development to serve the uses listed in **Table 8-9.**

The second phase of the reuse project will include additional treatment units to provide effluents with conditions to allow for artificial aquifer recharge in the vicinity of the airport. Column testing is being conducted to design recharge basins and to define the level of pollutant removal on the unsaturated layer.

8.5.5 Chile

Water resources in Chile are abundant (61,007 m^3/capita/year or 16.1 mg/capita/year), with a strong prevalence of surface water with inhomogeneous geographical distribution. In 1997, water supply and sewage coverage were comparable to those in Europe, with over 99 percent in urban areas and 90 percent in rural areas (Homsi, 2000). Moreover, 90.8 percent of rural settlements are equipped with water supply systems. Wastewater treatment coverage is lower, at about 20 percent, with strong governmental efforts for coverage to more than double that capacity in the near future. Consequently, the driving factor for water reuse at a national level, and in particular in large cities such as Santiago de Chile, is pollution control.

Wastewater reuse has been practiced for years near the large cities. In the past, 70 to 80 percent of Santiago's raw wastewater has been collected into an open drainage canal and then distributed for irrigation. The irrigated area immediately outside the city provided almost all the salad vegetables and low-growing fruits to the population of Santiago, having a large negative impact on public health. In order to improve this situation and implement sound water reuse practices, plans have been made to treat all the wastewater from greater Santiago in 3 large and 13 smaller sewage treatment plants. The first large facility, in operation since November 2001, El Trebol, has an average capacity of 380,000 m^3/d (100 mgd). Another treatment plant, La Farfana, will have a capacity of 760,000 m^3/d or 200 mgd when completed. Five smaller sewage treatment works are also in operation, all using activated sludge processes for treatment. Treatment facilities constructed before the 1980s mainly used stabilization ponds for treatment.

8.5.6 China

Water reuse in China primarily occurs when rivers downstream from cities are used for irrigation. Most pollution is produced in the industrialized cities; therefore, pollution control was first aimed at industries. Over the last 10 years, increasing attention has been paid to municipal wastewater treatment. In 2001, there were 452 wastewater treatment plants, of which approximately 307 provided secondary or higher treatment. These plants served all or parts of 200 cities of the 667 cities in China. The total volume of wastewater generated was 42.8 billion m^3 (11,300 billion gallons), of which industry generated 20.1 billion m^3 (5,300 billion gallons) (47 percent) and non-industrial (domestic, commercial, and institutional) sources generated 22.8 billion m^3 (53 percent). In 2001, approximately 35 percent of municipal wastewater received treatment before discharge. Wastewater sector investment is rising dramatically; in 1999 the annual expenditure rose to over 12 billion RMB ($1.5 billion), an 8-fold increase from 1996.

Taiyuan, a city of 2 million people and the capital of the Shanxi Province, is located approximately 400 kilometers (249 miles) southwest of Beijing on the Fen River, a tributary to the Yellow River. The city stretches for 29 kilometers (18 miles) within the narrow valley of the Fen River, where water availability is limited, sporadic, and greatly affected by high sediment loads from the Great Loess Plateau. Terracing for agriculture and destruction of natural ground cover on this plateau create large dust storms as well as limitations on water retention during major rainstorms.

Under the $2 billion Yellow River Diversion Project (YRDP), partially funded by the World Bank, water is being conveyed 200 kilometers (125 miles) by tunnels and aqueducts from a reservoir on the Yellow River and pumped to a head of 600 meters (1,970 feet) into the Fen River, upstream from Taiyuan. Previously, the groundwater aquifer beneath the city supplied much of the domestic demand, as well as the large industrial self-supplied water demands of the steel, coal, and chemical industries in the city. Industries have made considerable progress in water reuse, with 85 percent of industrial water demand achieved through internal treatment and reuse of process water. The chemical industry has built an advanced centralized treatment facility to provide an additional source for industrial water reuse as well as 2 large power plants that reuse all effluent in slurry pipelines to ash disposal reservoirs.

Taiyuan is implementing an environmental master plan, under which 7 enhanced secondary wastewater treatment plants will be built (or existing plants upgraded and expanded) to treat about 900,000 m^3/d (238 mgd) by 2010.

Table 8-9. Water Reuse at the Sao Paulo International Airport

Use	Flow	
	(m^3/day)	(gal/day)
Toilets and Urinals in Terminal 3	2,175	574,575
Cooling Towers (Air Conditioning)	480	126,800
Airplane Washing	50	13,200
Floor Washing	15	3,960
Irrigation	10	2,640
Total Flow	2,730	721,200

Approximately 500,000 m^3/d (132 mgd) of effluent from these plants will be reused via groundwater recharge from the Fen River ponds. The ponds were built as an urban amenity under a subsidized public works program to provide work for the unemployed during a period of economic restructuring and plant closures. The Fen River ponds stretch nearly 5 kilometers (3.1 miles) along the river, for a total volume of 2 million m^3 (528 mg), and occupy about half the width of the riverbed. Inflatable dams and floodgates on the slope of the Fen River allow floods in excess of the 2-year flood flow to be passed through to the ponds. The course alluvium of the river bottom under the ponds is expected to allow sufficient recharge to meet industrial demands through the existing self-supplied wells.

Groundwater levels have been dropping rapidly, and groundwater quality has deteriorated in the upper aquifer from the buildup of nitrates from untreated municipal wastewater, as well as salinity in the concentrated wastes in industrial wastewater after extensive recycling. As a result, water reuse from the aquifer recharge system will be primarily for nonpotable, industrial process water.

In order to prevent a large buildup of salinity in the groundwater, a portion of the effluent from the municipal wastewater treatment plants will be discharged into the Fen River. However, downstream irrigation demands greatly exceed the available stream flow, and eventually Taiyuan may face restrictions on consumptive use to re-establish stream flow in the lower portions of the Yellow River. Currently the Yellow River runs dry seasonally over the last 300 kilometers (186 miles) of its length, which is detrimental to major cities and agricultural areas in the densely developed water-scarce North China Plain.

8.5.7 Cyprus

Cyprus is a mediterranean island with a population of 700,000 and a vigorous tourism industry. The country is facing 2 major obstacles in its continued development: (1) a growing scarcity of water resources in the semi-arid regions of the country and, (2) degradation of water at its beaches. The government has recognized that a water reuse program would address both problems. In addition, it is expected that reclaimed water will provide a reliable alternative resource for irrigation, which draws 80 percent of the total water demand (300 Mm^3/year or 79,250 mg/year).

The 25 Mm^3/year (6,600 mg/year) of wastewater generated by the main cities will be collected and used for irrigation after tertiary treatment (Papadopoulos, 1995). Since transmission costs will be high, most of the reclaimed water, about 55 to 60 percent, will most likely be used for amenity purposes such irrigation of greens areas in hotels, gardens, parks, golf courses and other urban uses. A reclaimed water supply of about 10 Mm^3/d (2,640 mgd) is conservatively estimated to be available for agricultural irrigation.

The provisional water reuse standards in Cyprus are stricter than the WHO guidelines. The disinfection level required for urban uses with unrestricted public access is 50 FC/100 ml (80 percent of the time, with a maximum value of 100 FC/100 ml). For other uses with restricted access and for irrigation of food crops; the standard is 200 FC/100 ml (maximum 1000 FC/100 ml), while for irrigation of fodder and industrial crops, the guideline values are 1000 and 3000 FC/100 ml, respectively.

8.5.8 Egypt

Approximately 96 percent of Egypt is desert; rains are rare, even in winter, and occur only in the north. In addition, oases and wells are limited and cannot accommodate water needs in the regions where they exist. Egypt relies heavily on the Nile River, which supplies essentially all of the country's water.

Presently, wastewater production is estimated at 4,930 million m^3/year (1.3 mg/year). There are 121 municipal wastewater treatment plants operating in Egypt treating 1,640 million m^3/year (0.43 mg/year). A total of 42,000 hectares (104,000 acres) are irrigated with treated wastewater or blended water. Since 1900, wastewater has been used to cultivate orchards in a sandy soil area at El-Gabal El-Asfar village, near Cairo. This area has gradually increased to about 1,000 hectares (2,500 acres). The most readily available and economic source of water suitable for reuse is the wastewater effluent from Greater Cairo, Alexandria, and other major cities.

No reuse guidelines have yet been adopted in Egypt, but the 1984 martial law regulation prohibits the use of effluent for irrigating crops, unless treated to the required standards for agricultural drainage water. The irrigation of vegetables eaten raw with treated wastewater, regardless of its quality level, is also forbidden. As a result, a USAID-funded project is developing new codes for safe use of reclaimed water for irrigation of crops with a focus on those that cannot be contaminated, such as wood trees, palm trees, citrus, pomegranates, castor beans, olives, and field crops, such as lupins and beans. However, despite this code development, no adequate planning, monitoring, and control measures are being taken, and, because of this, spreading of Schistomiasis is quite common.

8.5.9 France

France's water resources availability is 3,047 m^3/capita/year (0.8 mg/capita/year) (Earth Trends 2001), and therefore, is considered to be self-sufficient. However, an uneven distribution of hydraulic resources and increasing global water demand have led to seasonal deficits in parts of the country. The average water consumption has increased by 21 percent in the past 10 years. The agricultural sector has experienced the greatest increase of water use, 42 percent, mainly due to an increase in land irrigation. Water consumption has also increased in resort areas where water is needed to irrigate golf courses and landscape areas. The industrial sector is the only sector that has seen a decrease in water consumption, due to increasing efforts to reuse industrial effluents and use more water-efficient technologies. Recently, there has been a reduction in domestic water consumption.

France has been practicing nonpotable water reclamation since the 19th century. Its oldest projects are the Achères water reclamation plant (near Paris) and the Reims plant**.** The main drivers for water reuse in France are to: (1) compensate for water deficiencies, (2) improve public health, (3) to protect the environment, and (4) eliminate contamination in recreational and shellfish farming areas along the Atlantic coast. The majority of water reuse projects are found in the islands and in coastal areas in the southern part of the country.

Numerous cases of unplanned indirect potable reuse exist in France, where surface water, diluted with wastewater, is used for potable water supply. An example is Aubergenville, in the Paris region, where the Seine River, which is 25 percent wastewater effluent, is treated and used to recharge the drinking water aquifer.

Clermont Ferrand is a large agricultural reuse project that was implemented in 1999 as a response to water shortages and economic concerns. The wastewater treatment facility consists of an activated sludge process and maturation ponds for disinfection. Over 10,000 m^3/d (2.6 mgd) are used to irrigate 750 hectares (1,850 acres) of maize.

One of the first examples in Europe of integrated water management with water reuse is on Noirmoutier Island. The lack of water resources, the 10-fold increase in tourist population during the summer, and the intensive agricultural activities required water reuse. Wastewater treatment on the island is achieved through 2 treatment plants with a total capacity of 6,100 m^3/d (1.6 mgd). The plants have activated sludge systems followed by maturation ponds for storage and disinfection. Thirty percent of the treated wastewater (0.33 Mm^3/year) is used for the irrigation of 500 hectares (1,235 acres) of vegetable crops. There are plans to reuse 100 percent of the wastewater flow in the near future.

The country's regulatory framework (Circular n° 51 of July 22, 1991, of the Ministry of Health) is based on the WHO guidelines (1989). But France's regulations are more stringent having additional requirements concerning irrigation management, timing, distance and other measures for preventing health risks related to human exposure and negative environmental impacts (i.e. the potential contamination of groundwater). New water reuse guidelines are under preparation with the introduction of some new microbiological indicators for unrestricted irrigation (i.e. Salmonella, Taenia eggs), as well as more stringent operational restrictions.

8.5.10 Greece

Greece has a severe water imbalance, particularly in the summer months, due to low precipitation and increased demands for irrigation and water use. Water demand in Greece has increased tremendously over the past 50 years (Tchobanoglous and Angelakis, 1996). Despite adequate precipitation, water shortages are often experienced due to temporal and regional variations in precipitation, the increased water demand during the summer months, and the difficulty of transporting water through the mountainous terrain. As a result, the integration of water reuse into the water resources management is becoming a very important issue.

In 2000, almost 60 percent of the population was connected to 270 wastewater treatment plants, with a total capacity of 1.30 Mm^3/d (345 mgd). An analysis of treated domestic wastewater distribution of showed that more than 83 percent of wastewater effluent is produced in regions with a deficient water balance (Tchobanoglous and Angelakis, 1996). This indicates that water reuse in these areas would satisfy a real water demand. Another important factor driving the use of reclaimed water is that 88 percent of the wastewater effluents are located at a distance of less than 5 kilometers (3.1 miles) from farmland needing irrigation water; therefore, the additional cost for irrigation with reclaimed water would be relatively low.

According to Tsagarakis *et al*. (2000), over 15 wastewater treatment plants are planning to reuse their effluents for agricultural irrigation. The major water reuse projects being planned or constructed are listed in **Table 8-10**. Unplanned reuse still occurs in some regions, where wastewater is discharged to intermittent rivers and, after infiltration, is pumped through adjacent wells by farmers.

Guidelines for water reuse are under consideration by the Ministry of Environment and Public Works (Angelakis

Table 8-10. Major Reuse Projects

Plant Name	Capacity		Uses
	m^3/day	mgd	
Levadia	3,500	0.925	Irrigation of cotton
Amfisa	400	0.106	Olive tree irrigation
Palecastro	280	0.74	Storage, olive tree Irrigation
Chalkida	13,000	3.434	Landscape and Forestry irrigation
Karistos	1,450	0.383	Landscape and Forestry irrigation
Ierisos	1,200	0.317	Landscape and Forestry irrigation
Agios Konstantinos	200	0.053	Landscape and Forestry irrigation
Kentarchos	100	0.026	Landscape and Forestry irrigation

et al., 2000). Six water reuse categories are being considered: nonpotable urban, agriculture, aquaculture, industrial, environmental, and groundwater recharge. The criteria are more stringent requirements than the WHO guidelines. Secondary effluent quality criteria are used for discharging purposes (No E1b/221/65 Health Arrangement Action) and are independent of the disposal, reclamation, and reuse effort.

8.5.11 India

India is the second most populous country of the world, with a current population of over 1 billion that is projected to increase to 1.5 billion by 2050 (Worldwatch Institute, 1999). Almost 30 percent of the population lives in urban mega-cities, in particular, in the 7 giant conglomerates of Mumbai (formerly Bombay) (12.57 million), Calcutta (Kolkata) (10.92 million), Delhi (8.38 million), Chennai (formerly Madras) (5.36 million), Bangalore (4.09 million), Hyderabad (6 million), and Ahmedabad (3 million). Fast depletion of groundwater reserves, coupled with India's severe water pollution, have put India in a challenging position to supply adequate amounts of water to their growing population. In 2000, India's total renewable water resources were estimated at 1,244 m^3/capita/year (328,630 gallons/capita/year) (Earth Trends, 2001) and it was estimated that 40 percent of India's water resources were being withdrawn, with the majority of that volume (92 percent), used for agricultural irrigation.

As a result of the fast-growing urban population, service infrastructure is insufficient to ensure public health. In fact, about 15 percent of the urban population does not have access to safe drinking water and about 50 percent is not serviced by sanitary sewers. In 1997, the total volume of wastewater generated in India was 17 Mm^3/d (4,500 mgd), of which 72 percent was collected and only 24 percent was ever treated. These conditions cause a high number of waterborne diseases in the country (more than 30 million life years according to the World Bank).

The capital city of Delhi is one illustration of failing service infrastructure and deteriorating environment. The growing population in Delhi has led to an increase in the volume of wastewater, yet the current treatment capacity is only about 1.3 Mm^3/d (3,400 mgd) – which is only 73 percent of the wastewater generated. Another example is Mumbai, where 2.3 Mm^3/d (608 mgd) of raw sewage is discharged into the Arabian Sea. However, there have been some attempts at rectifying these situations. The large, $300 million, Bombay Sewage Disposal Project was approved in 1995 with the financial support of the World Bank. Other efforts have been made in the Calcutta metropolitan area, where 13 sewage treatment plants have been constructed with a total capacity of 386,000 m^3/d (102 mgd) using either activated sludge processes, trickling filters, or oxidation ponds. In addition, the Ganges River program is to include treatment facilities for 6 cities in Uttar Pradesh that will incorporate reuse for agriculture and forestry.

In 1985, over 73,000 hectares (180,000 acres) of land were irrigated with wastewater on at least 200 sewage farms. There has been a dramatic increase in wastewater volumes discharged and used for agricultural irrigation in India. With its current population, Hyderabad can supply wastewater to irrigate an estimated 40,000 hectares (99,000 acres). The law prohibits irrigation of salad vegetables with wastewater, yet the prohibited practice is widespread and government agencies reportedly do not actively enforce regulations governing reuse. Furthermore, in many states there is no microbiological standard and hence no parameter to control the level of treatment. Enteric diseases, anemia, and gastrointestinal illnesses are high among sewage farm workers. Consumers of salad and vegetable crops are also at risk.

8.5.11.1 Hyderabad, India

Hyderabad, the capital city of Andhra Pradesh, is the fifth largest and the fastest growing city in India with 6 million inhabitants (2001). The city produces over 700,000 m^3 (185 mg) of wastewater per day, of which less then 4 percent receives secondary treatment. The remaining 95 percent of the wastewater is disposed, untreated in the Musi River. The Musi River is the main source of irrigation water for over 40,000 hectares (98,840 acres) of agricultural land. Agriculture is the sole livelihood of over 40,000 farming families living within a 50-kilometer (31-mile) radius of Hyderabad.

Downstream of Hyderabad, the Musi River water is diverted through a system of weirs into irrigation canals (see photo) that were originally designed to retain water for the dry season after the monsoon rain. Farming communities along the Musi River experience negative and positive impacts from the discharge of wastewater into the river. Perceived negative impacts include an increase in reported fever cases, skin rash, joint aches, and stomach problems. Positive impacts include savings in chemical fertilizer application and larger crops as a result of a year-round availability of water, which without the addition of wastewater, would have been confined to the monsoon season. The main crops grown are fodder, rice, and bananas, as well as different varieties of spinach and other vegetables. Data reported that water samples taken out of the Musi River, 40 kilometers (25 miles) downstream of Hyderabad, have normal river water quality parameter readings including a gradual reduction in BOD, COD, and coliform. The coliform counts reported were within the WHO guidelines set for unrestricted irrigation.

8.5.12 Iran

Iran is one of the largest countries in the Middle East, with an area of more than 165 million hectares (407 million acres) and a population of over 60 million (Shanehsaz *et al.,* 2001). The average annual precipitation over the country is less than 250 mm (10 inches). Distribution of rainfall in Iran is not uniform, with some very urbanized areas receiving even less than the average annual precipitation.

In 1994, the volume of municipal wastewater generated in all urban and rural areas of the country (potentially reclaimable as a water resource if a collection system were in place) was estimated to be 3,100 Mm^3/year (2.5 million acre-feet per year), and projected to increase to 5,900 Mm^3/year (4.8 million acre-feet per year) by 2021. [Agricultural return flows and industrial wastewaters are not included in these figures.] These immense volumes are now largely disposed of at the point of generation, through cesspits, without treatment. If collected, properly treated, distributed, and safely utilized, these volumes of water could go a long way toward meeting the burgeoning demands for agricultural and industrial water demand of the nation. Planned water reuse projects currently produce 154 Mm^3/year (125,000 acre-feet per year) of reclaimed water.

In fact, recently, the government of Iran approved a recommendation to establish and implement programs for, among other water-related initiatives, comprehensive reclamation and use of non-conventional water resources—such as reclaimed water. The public also accepts water reclamation and reuse as a sensible way to maximize the use of a limited resource. In the past, effluent was used primarily to fertilize the soil, but now wastewater effluent is increasingly used for improving water use efficiency, surface and groundwater pollution prevention, and to compensate for a shortage of irrigation water. Other driving forces for water reuse include expansion of greenbelts, soil erosion prevention by growing plants and improving soil quality, and control of the desertification process.

Hyderabad, India – wastewater being diverted over weir into irrigation canals. Source: International Water Management Institute

Iranian farmers generally consider wastewater an acceptable water resource for irrigation. There are studies in Iran examining the use of treated effluent for irrigation water in the suburban farms, mainly for fodder crops such as corn, millet, and alfalfa. Systematic studies have shown that there is a significant decrease in water use and fertilizer consumption due to nutrients in the effluent.

At present, there is no national standard for the reuse of treated wastewater. The only existing wastewater code in Iran is the "Effluent Discharge Standard" developed by the Department of the Environment in 1994. This standard determines the allowable effluent discharges to surface waters, cesspits, and agricultural irrigation; however, the standard does not provide any criteria for the use of reclaimed water for industrial use, fisheries, or recreational activities. Microbiological criteria in this standard are inadequate for the purposes of water reclamation and reuse; therefore, reliable international standards, such as those developed by the WHO and by the EPA, are currently used to regulate water reuse. The responsibility and authority for water reuse is scattered and fragmented, as it is in many other parts of the world. Institutions responsible for the management of various aspects of water, wastewater, water reclamation and reuse in Iran are the Ministry of the Energy, Ministry of *Jihad* and Agriculture, Ministry of Health and Medical Education, Ministry of Industries and Mines, and the Department of the Environment.

Despite governmental edicts prohibiting the use of untreated wastewater in irrigation and agriculture, there are still some places in Iran where the farmers use raw wastewater, due to a shortage of fresh water supplies. Unplanned use of wastewater is observed in cities with no sanitary sewage systems and no wastewater treatment plants. The government, at all management levels, has struggled to maximize the benefits of reuse and is working to accomplish this by giving appropriate priorities to water use in various sectors, and by encouraging wastewater reclamation and reuse through allocation of the necessary financial resources. Considering that wastewater treatment and water reclamation are relatively new in Iran, 2 of the most important approaches used by the government are economical incentives and management tools. Operational permits are issued for the use of surface water or groundwater, municipal distribution networks, and the continuance of previously issued permits. These permits are now conditioned with requirements for implementation of sewage systems and wastewater treatment plants. Until such systems are implemented, entities that consume water are required to pay penalties in proportion to their discharge volumes and based on established tariffs. A percentage of the income from the collected penalties is channeled to the Department of Energy to fund water conservation and wastewater treatment construction projects.

8.5.13 Israel

The acute shortage of fresh water throughout most of Israel prompted the development of a nationwide integrated water management system. As a result of the water crisis, with repetitive droughts between 1996 and 2002, Israel turned to water conservation and alternative water resources including the most widely practiced form of water reuse, reclaiming municipal water from medium and large cities for irrigation of agricultural crops.

In several water reuse projects in Israel, deep, surface reservoirs are used to store effluent during the winter season and the water is then used during the summer irrigation season. There are approximately 200 of these reservoirs in operation throughout the country with a total storage capacity of 150 Mm^3 (40,000 mg). Most of these reservoirs also serve as surface water storage and additional treatment. The oldest, and by far the largest reuse project, is the Dan Region Project, which incorporates soil-aquifer treatment (SAT) and storage in a groundwater aquifer.

Water reuse represents approximately 10 percent of the total national water supply and almost 20 percent of the total water supply for irrigation. Nearly 70 percent of the municipal wastewater collected is treated and reused for irrigation. As a result of this nationwide effort, Israel currently supports its increasing population, industrial growth, and intensive irrigation demand with a water supply of less than 400 m^3/capita/year (105,700 gallons/capita/year), while the benchmark value for water stress is available renewable water resources of 1700m^3/capita/year (449,000 gallons/capita/year). Israel's objective is to treat and reuse most of its wastewater by 2010 (400 Mm^3 or 106,000 mg per year, 20 percent of the country's total water resources). Most of the reclaimed water would be used for the irrigation of crops and animal fodder in accordance with the regulations put forth by the Ministry of Health.

Pumps transfer water from the withdrawal wells to irrigation zones in the Negev Desert, Israel. Photo courtesy of Bahman Sheikh

The 2 largest reuse projects are the Dan Region Reclamation Scheme and the Kishon Scheme. The Kishon facilities treat 32 Mm^3/year (8,450 mg/year) of wastewater from the Haifa metropolitan area using a conventional activated sludge system. After treatment, the reclaimed water is conveyed to the Yiszre'el Valley, approximately 30 kilometers (18.6 miles) east of Haifa, where it is blended with local waste and stormwater and then stored in a 12-Mm^3 (3,170-mg) reservoir for summer irrigation of 15,000 hectares (37,000 acres) of cotton and other non-edible crops. The Dan Region reuse system serves the Tel Aviv metropolitan area of approximately 1.7 million inhabitants. The facilities include a 120-Mm^3/year (31,700-mg/year) mechanical biological plant (Soreq wastewater treatment plant). After biological treatment, the wastewater is discharged to aquifer recharge basins and stored in the aquifer. The reclaimed water is then pumped from recovery wells and conveyed to irrigation areas on the southern coastal plain and the northern Negev area (see photo). Some areas only receive auxiliary irrigation of 4,000 to 8,000 m^3/hectares/year (0.4 to 0.8 mg/acres/year); while more intensely irrigated areas use 10,000 to 20,000 m^3/hectares/year (1.1 to 2.2 mg/acres/year).

There are 3 other significant reuse projects in the Jeezrael Valley (8 Mm^3/year or 2,100 mg/year), Gedera (1.5 Mm^3/year or 400 mg/year), and Getaot Kibbutz (0.14 Mm^3/year or 37 mg/year). All 3 of these reuse projects produce reclaimed water for the irrigation of over 40,000 hectares (98,840 acres) of agricultural lands.

8.5.14 Italy

Like most Mediterranean regions, southern Italy (particularly Sicily, Sardinia, and Puglia) suffers from water shortage and lack of quality water due to recurrent droughts (Barbagallo *et al.,* 2001). In addition, wastewater discharge into rivers or the sea has lead to significant environmental problems and eutrophication. Available water resources are estimated to be 2,700 m^3/capita/year (713,260 gallons/capita/year), with a water volume of about 155 billion m^3 (41,000 billion gallons). According to the recent estimates, the potential water resources in Italy are less than 50 billion m^3 (13,200 billion gallons) when considering the actual hydraulic infrastructures with relatively low water availability of about 928 m^3/capita/year (245,150 gallons/capita/year).

The deficient and unreliable supply of irrigation water, besides reducing production most years, has strongly limited irrigation development. Forecasts for irrigation water demand show steady increases in many areas, not only in southern Italy and the islands.

The reuse of untreated wastewater in Italy has been practiced since the beginning of the 20th century. Among the oldest and noted cases is the "marcite", where water from the Vettabia River, which has a high content of industrial and urban raw wastewater, is used for irrigation. However, this practice has been decreasing due to poor water quality. The only negative impact reported is an instance where a high concentration of boron damaged very sensitive crops, such as citrus.

The present lack of water resources and the growing demand for domestic, industrial, and agricultural consumption has prompted research into non-conventional supplies. Reclaimed water is beginning to be considered a cost competitive source, playing an increasingly important role in water resource management. A survey of Italian treatment plants estimated the total treated effluent flow to be 2400 Mm^3/year (634,000 mg/year), all estimated to be potential reuse water. The medium to large plants in Italy treat approximately 60 percent of the urban wastewater flow and can produce reclaimed water to an adequate quality at a reasonable cost.

Currently, reuse water is used mainly for agricultural irrigation of over 4,000 hectares (9,800 acres) of land. However, the controlled reuse of municipal wastewater in agriculture is not yet developed in most Italian regions because of stringent legislation, which ignores the findings of recent research works and experiences of uncontrolled reuse in Southern Italy. One of the largest reuse projects was implemented in Emilia Romagna where over 1,250 m^3/d (0.3 mgd) of treated effluent from the towns of Castiglione, Cesena, Casenatico, Cervia, and Gatteo are used for irrigation of more than 400 hectares (980 acres).

According to a recent survey (Barbagallo *et al*., 2001), 16 new water reuse projects for irrigation purposes have been selected for implementation in water-scarce regions. In Sicily, where uncontrolled wastewater reuse is very common, several new reuse systems have been planned, using seasonal storage reservoirs. In Grammichele, about 1,500 m^3/d (0.4 mgd) of reclaimed water will be used for the irrigation of citrus orchards. Recently, 2 other projects have been authorized and financed on Palermo and Gela, where reuse water will be used for irrigation of several thousand hectares.

Another industrial reuse project is at the Turin sewage treatment plant, which treats 500,000 m^3/d (132 mgd) with nitrogen and phosphorus removal. Approximately 8 percent of the effluent will undergo tertiary treatment, filtration and chlorination, for agricultural and industrial reuse.

8.5.15 Japan

Because of the country's density and limited water resources, water reclamation and reuse programs are not new to Japan. Only 40 percent of Japan's total population (including the rural population) is sewered; however, by 1995, 89.6 percent of cities larger than 50,000 people were sewered, and 72 percent of the inhabitants of these cities were served with a sewage collection system. Therefore, buildings being retrofitted for flush toilets and the construction of new buildings offer excellent opportunities for reuse. Initially, the country's reuse program provided reclaimed water to multi-family, commercial, and school buildings, with a reclamation plant treating all of the wastewater for use in toilet-flushing and other incidental nonpotable purposes. Later, municipal treatment works and reclaimed water systems were used together, as part of a dual system, providing more effective and economical treatment than individual reclamation facilities.

In 1998, reclaimed water use in Japan was 130 Mm^3/year (94 mgd), according to Ogoshi *et al*. (2000) with distribution as shown in **Table 8-11**. At that time, about 40 percent of the reclaimed water was being distributed in dual systems. Of this more than 1/3 was being used for toilet flushing, and about 15 percent each for urban irrigation and cleansing. A wide variety of buildings were fitted for reclaimed water use, with schools and office buildings being most numerous. In Tokyo, the use of reclaimed water is mandated in all new buildings larger in floor area than 30,000 m^2 (300,000 ft^2).

Japan offers a very good reuse model for cities in developing countries because its historical usage is directly related to meeting urban water needs rather than only agricultural irrigation requirements. In addition, the country's reclaimed water quality requirements are different from those in the U.S., as they are more stringent for coliform counts for unrestricted use, while less restrictive for other applications.

Examples of large area water reclamation systems in Japan can be found in Chiba Prefecture Kobe City, and Fukuoka City. Outside the city limits of each of these urban areas, streams have been augmented, parks and agricultural areas have been irrigated, and greenbelts established with reclaimed water (Ogoshi *et al*., 2000). The price of reclaimed water in these cities ranges from \$0.83/m^3 for residential use to \$2.99/m^3 for business and other uses. This compares with a potable water price range of \$1.08 to \$3.99/m^3.

8.5.16 Jordan

Jordan has very limited renewable water resources of only 102 m^3/capita/year (26,950 gallons/capita/year) (World Water Resources, 2000-2001), which is basically at the survival level (see Section 8.2.1). As a result, mobilization of non-conventional water resources is one of the most important measures that have been proposed to meet the increasing water demand of the growing population (3.6 percent/year, 6.5 million expected in 2010).

Over 63 percent of the Jordanian population is connected to sewage systems. Seventeen wastewater treatment plants are in operation, with an overall capacity of 82 Mm^3/year (21,700 mg/year). The largest facilities (greater than 4,000 m^3/d or 1.1 mgd) are As-Samra, Baqa's, Wadi Arab, Irbid, and Madaba. Stabilization ponds and activated sludge processes are the most common treatment processes in addition to a few trickling filter facilities.

More than 70 Mm^3 (57,000 acre-feet or 18,500 mg) of Jordan's reclaimed water, around 10 percent of the total water supply, is either directly or indirectly reused each year. By the year 2020, the expected available volume of treated wastewater is estimated to be 265 Mm^3/year (70,000 mg/year), which is about 25 percent of the total water available for irrigation. To date, the majority of the reuse has been unplanned and indirect, where the reclaimed water is discharged to the environment and, after mixing with natural surface water supplies and freshwater supplies, used for agriculture downstream, primarily in parts of the Jordan Valley. The direct use of reclaimed water in the immediate vicinity or adjacent to the wastewater treatment plants is generally under the jurisdiction of the Water Authority of Jordan (WAJ), which is the entity that plans, builds, owns, operates, and maintains the plants. The majority of these sites are pilot projects with some research and limited commercial viability. A few direct water reuse operations, such as the

Wadi Musa secondary treatment plant and storage ponds serving communities in the vicinity of Petra, Jordan. Photo courtesy of Bahman Sheikh

Table 8-11. Uses of Reclaimed Water in Japan

Use	Percent	Mm^3/year	mg/year
Environmental Water	54%	63.9	16,882.4
Agricultural Irrigation	13%	15.9	4,200.8
Snow Melting	13%	15.3	4,042.3
Industrial Water	11%	12.6	3,328.9
Cleansing Water	9%	11.2	2,959.0

Source: Oqoshi *et al.*, 2000.

date palm plantations receiving reclaimed water from the Aqaba wastewater treatment plant, are separate and viable enterprises.

In recent years, with an increasing population and industrialization, planned water reuse is being viewed as an important component of maximizing Jordan's scarce water resources. As a result, the government of Jordan, with support from USAID, has been examining water reuse and its application in the integrated management of Jordan's water resources, particularly to alleviate the demand on fresh water. The Water Resource Policy Support activity includes policy support and broad-based stakeholder participation on water reuse, specifically in the Amman-Zarqa Basin (McCornick *et al.,* 2002). To further promote the commercial viability of direct water reuse, the government of Jordan, with support from USAID, also revisited the existing water reuse standards (Sheikh, 2001). Senior international water reuse and standards experts were consulted in coordination with government, agriculture, industry, and technical representatives, whose participation helped develop an appreciation of the constraints and concerns faced by all parties with respect to reclaimed water use. Jordan is now implementing a program that will demonstrate that direct water reuse is reliable, commercially viable, socially acceptable, environmentally sustainable, and safe. The program is focusing on 3 sites in Jordan including: Wadi Musa (see photo), Aqaba, and Jordan University of Science and Technology, each of which is at a different stage of development in wastewater treatment and reuse.

8.5.17 Kuwait

With a population estimated at about 2 million, most of Kuwait can be considered urban. The country is arid, with average annual rainfall less than 12.5 cm (5 inches). With no surface sources, water is drawn from groundwater at the rate of about 2270 m^3/d (0.6 mgd) for producing bottled water and for adding minerals to desalinized seawater from the Persian Gulf. Most water needs are met by desalination. About 90 percent of the urban population is connected to a central sewage system.

According to **Table 8-12**, irrigation accounts for approximately 60 percent of Kuwait's water use, while approximately 37 percent is withdrawn for domestic use. Irrigation water is primarily supplied from groundwater (61 percent) and reclaimed water (34 percent).

In 1994, the total volume of collected wastewater was 119 Mm^3/year (31,400 mg/year), 103 Mm^3/year (27,200 mg/year) of which was treated. The 3 main municipal treatment plants are Ardhiya, Reqqa, and Jahra, with a total capacity of more than 303,000 m^3/d (80 mgd). Tertiary treatment – activated sludge, filtration, and chlorine disinfection – is provided. And while Kuwait has been practicing water reclamation and reuse for over 20 years as a means of extending its limited natural water supply, only about 10 percent of treated effluent is reused.

While the use of reclaimed water for landscape irrigation is growing in urban areas, the main reuse application is agricultural irrigation (4,470 hectares or 11,046 acres in 1997), representing 25 percent of the total irrigated area. Reclaimed water is only allowed for the irrigation of vegetables eaten cooked (potatoes and cauliflower), industrial crops, forage crops (alfalfa and barley), and irrigation of highway landscapes. **Table 8-13** details the effluent quality standards established by the Ministry of Public Works for water reuse.

The percentage of reclaimed water used for irrigation in Kuwait is relatively high; nevertheless, groundwater supplies used for irrigation are being stressed through excessive pumping. The result is increasing salinity of irrigation water. Irrigated lands are also experiencing salinization due to evaporation. In response to these irrigation concerns, Kuwait signed a forward-looking, 30-year, build-operate-transfer (BOT) concession contract in May 2002 for the financing, design, construction, and operation of a 375,000-m^3/d (99-mgd) wastewater treatment and reclamation plant. The plant, due to commence operation in 2005, is located at Sulaibiya, near one of the most productive agricultural areas of Kuwait. Product water from the Sulaibiya plant must meet the concession contract requirements presented in **Table 8-14**.

The product water from this plant will be very high quality and will allow Kuwait several choices for end use including unrestricted irrigation and replenishment of irrigation groundwater supplies. The Sulaibiya plant will achieve the high quality product water through the application of advanced treatment processes – biological nitrogen and phosphorus removal, followed by ultrafiltration and reverse-osmosis treatment.

8.5.18 Mexico

Like other Latin American countries, Mexico faces a major challenge in terms of providing drinking water, sewage connection, and wastewater treatment, due to the need to strengthen and expand its economic and social development. Therefore, efforts to reuse water for different purposes are extremely important to solving the increasing water shortage and environmental problems. Mexico has 314 catchment areas with an average water availability of 4,136 m^3/capita/year (1.1 mg/capita/year) (Water Resources 2000-2001) with uneven distribution. Average rainfall is 777 mm (30.6 inches) per year, and most of it occurs over only 4 months per year.

At the national level, the rates of coverage for drinking water and sewage connection in December 1998 were 86 percent and 72 percent, respectively. However, high discrepancies exist for the different regions, in particular for sewer connections with 32 percent for small communities and 92 percent for large cities. Approximately 22 percent of all the wastewater flow from urban centers throughout the country, estimated at 187 m^3/s (49,400 gallons/s), are treated at 194 sewage treatment plants. The total urban wastewaters produced in Mexico are estimated to be 14.7 Mm^3/d (3,880 mgd), of which 25 percent are currently treated prior to discharge.

Towns and cities across Mexico generate wastewater that is reused in agriculture (Scott *et al,* 2000). The government has mandated treatment and wastewater quality standards that are set by the type of receiving waters. One of the major examples of agricultural reuse is Mexico City. Almost all collected raw wastewater (45 to 300 m^3/s dry and wet flows, respectively, or 11,900 to 79,250 gallons/s), is reused for irrigation of over 85,000 hectares (210,000 acres) of various crops (Jiménez, 2001). Of the total wastewater generated, 4.25 m^3/s (367,000 m^3/d or 97 mgd) is reused for urban uses (filling recreational lakes, irrigating green areas, car washing, 3.2 m^3/s (845 gallons/s) is used for filling a part of a dry lake called Texcoco, and for other local uses, and 45 m^3/s (12,000 gallons/s) is transported 65 kilometers (40 miles) to the Mezquital Valley for irrigation. The reuse of this wastewater for irrigation represents an opportunity for the development of one of the most productive irrigation districts in the country; however, health problems also are also a result from this practice.

Although the necessity to treat wastewater is obvious, when the Mexican government started a wastewater improvement program for the Valley of Mexico, the farmers from the Mezquital Valley were opposed to it. The main argument was to keep the organics and nutrients (carbon, nitrogen, phosphorus, and other micronutrients) as fertilizer for the crops.

Several projects have been conducted to determine the most appropriate treatment that would ensure adequate disinfection (to minimize epidemiological problems and illnesses), but keeping the nutrients in the reclaimed water to preserve the fertilizing property. According to the results obtained, it is concluded that advanced primary treatment (coagulation/flocculation plus disinfection) produces water of a consistent quality, independent of the

Table 8-12. Water Withdrawal in Kuwait

Water Use	Annual Quantity	
	(Mm^3)	(mg)
Agricultural	324	85,600
Domestic	201	53,100
Industrial	13	3,435

Source: Food and Agriculture Organization of the United Nations, 1997

Table 8-13. Reclaimed Water Standards in Kuwait

Parameter	Irrigation of Fodder and Food Crops Not Eaten Raw, Forestland	Irrigation of Food Crops Eaten Raw
Level of Treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD (mg/L)	10	10
COD (mg/L)	40	40
Chlorine Residual (mg/L), After 12 hours at 20° C	1	1
Coliform Bacteria (count/100 ml)	10,000	100

Table 8-14. Effluent Quality Standards from the Sulaibiya Treatment and Reclamation Plant

Characteristics	Monthly Average Value
pH	6 to 9
TDS (mg/l)	<100
TSS (mg/l)	<1
VSS (mg/l)	<1
BOD (mg/l)	<1
NH_3-N (mg/l)	<1
NO_3-N (mg/l)	<1
PO_4-P (mg/l)	2
Sulfide (mg/l)	<0.1
Oil and Grease (mg/l)	<0.05
TOC (mg/l)	<2
Hardness (mg/l) as $CaCO_3$	<10
Color (unit)	<1
Enteric Viruses (Geometric Mean)	5
Total Coliforms (colonies/100 ml)	<2.2

Source: State of Kuwait, Ministry of Finance (2000).

variation in wastewater quality in the influent. This process may also be used for the treatment of wastewater destined for reuse in agriculture in accordance with the quality standards established.

Another growing issue in Mexico is the reuse of municipal wastewater in industry. For example, in the Monterrey metropolitan area, 1.2 m^3/s (317 gallons/s) of reclaimed water (104,000 m^3/d, 16 percent of the total volume of treated municipal wastewater), is reused as make-up water in cooling towers in 15 industries. Besides increasing pressure on water resources, this project is driven by economic concerns. The competitive cost of reclaimed water is \$0.3/m^3, compared to conventional sources of groundwater at \$0.7/m^3, and potable water at \$1.4/m^3.

The improvement of sanitation, water resource management and water reuse in Mexico requires appropriate administrative reorganization. One possible solution is the public-private partnership that was successfully established in Monterrey (Agua Industrial de Monterrey Sociedad de Usuarios) and more recently in Culiacan.

8.5.19 Morocco

Despite the influence of the Atlantic Ocean, which contributes to the area's relatively abundant precipitation, Morocco is an arid to semi-arid country. Out of 150 billion m^3 (120 million acre-feet/year or 40,000 billion gallons/year) of annual rainfall, only 30 billion m^3 (24 MAFY or 7,925 billion gallons/year) are estimated to be usable (70 percent as surface water and 30 percent from aquifers). In addition, these resources are unevenly distributed. The catchment areas of the Sebou, Bou Regreg, and Oum er Rbia wadis alone represent 2/3 of the hydraulic potential of the country (Food and Agriculture Organization of the United Nations, 2001).

Approximately 11.5 billion m^3 (9 million acre-feet per year or 3,000 billion gallons/year) of water are used annually, including 3.5 billion m^3 (3 million acre-feet per year or 925 billion gallons/year) from groundwater. Nearly 93 percent of this amount is used to irrigate 1.2 million hectares (3 million acres), including 850,000 hectares (2 million acres) irrigated more or less permanently throughout the year.

Most Moroccan towns are equipped with sewage networks that also collect industrial effluent. The volumes of wastewater collected were estimated at 500 Mm^3/year (360 mgd) in 1993 and are expected to reach 700 Mm^3/year (500 mgd) in 2020. For Casablanca alone, the annual production of wastewater is estimated at 250 Mm^3/year (180 mgd) in 1991, with forecasts of around 350 Mm^3 (275 mgd) in 2010. However, out of the 60 largest towns, only 7 have treatment plants, and the design and operation of those plants are considered insufficient.

Most of the wastewater produced by inland towns is reused, mainly, as raw or insufficiently treated wastewater, to irrigate about 8,000 hectares (20,000 acres). Sometimes the wastewater is mixed with water from the wadis, into which it spills. A high proportion of the remaining water is discharged to the sea. The irrigated crops are mainly fodder crops (4 harvests of corn per year around Marrakech), fruit, cereals, and produce. If irrigated with wastewater, the growing and selling of vegetables to be eater raw is prohibited.

The largest water reuse project in Morocco was implemented in 1997 in Ben Slimane (near Rabat), where 5600 m^3/d (1.5 mgd) of wastewater is treated by stabilization ponds (anaerobic, facultative, and maturation ponds) and the disinfected effluent (absence of helminth eggs, less than 20 CF/100 ml) is used for golf course irrigation during the summer (average volume of reused water 1000 m^3/d or 0.26 mgd). The country does not yet have any specific wastewater reuse regulations and usually refers to the WHO recommendations.

The lack of wastewater treatment before reuse in inland cities has resulted in adverse health impacts, and a high incidence of waterborne diseases exist in Morocco. Improvement in wastewater reuse methods and the quality of reuse water for irrigation is recognized as essential. Major improvements are urgently needed because of the strong migration of the rural population towards the towns and the very rapid demographic expansion.

8.5.19.1 Drarga, Morocco

The Morocco Water Resources Sustainability (WRS) Activity is a USAID-funded project that started in July, 1996. The objectives of WRS are: (1) to assist the government of Morocco in undertaking water policy reforms, (2) to implement pilot demonstrations that introduce technologies which will foster the sustainability of water resources, and (3) to broaden public participation in water resources management.

The Commune of Drarga, near Agadir, in southern Morocco, is rapidly expanding. The current population of 10,000 is expected to double over the next few years. Prior to the start of the WRS project, the town of Drarga had a potable water distribution and wastewater collection system; however, raw wastewater was being discharged into the environment without any treatment, creating large cesspools and contaminating drinking water sources.

The 1,000-m^3/d (0.26-mgd) Drarga wastewater treatment plant uses a re-circulating sand filtration system. After screening, the influent flow is treated in anaerobic basins with an average hydraulic retention time of 3 days. The flow is then sent to equalization storage where it is adjusted for release to sand filters. The third step of the treatment process, after the sand filters, is denitrification. Finally, the treated flow is sent to reed beds where the root systems of the reeds provide further filtration. The final effluent is stored in a storage basin before being pumped to irrigate adjacent fields.

The implementation of a public participation program has been one of the cornerstones of the Drarga project. The fact that the public was consulted throughout each step of the project has resulted in overall public support for the project. Public opinion even led to a change in the plant's location.

Another key element of the Drarga pilot project was the establishment of an institutional partnership. A local steering committee, made up of all of the institutions involved with various aspects of water management at the local level, was created at the beginning of the project. The role of the steering committee was to follow each step of the pilot project and to provide assistance, when necessary, based on their specific area of expertise. After construction, a technical oversight committee was set up to oversee plant operations.

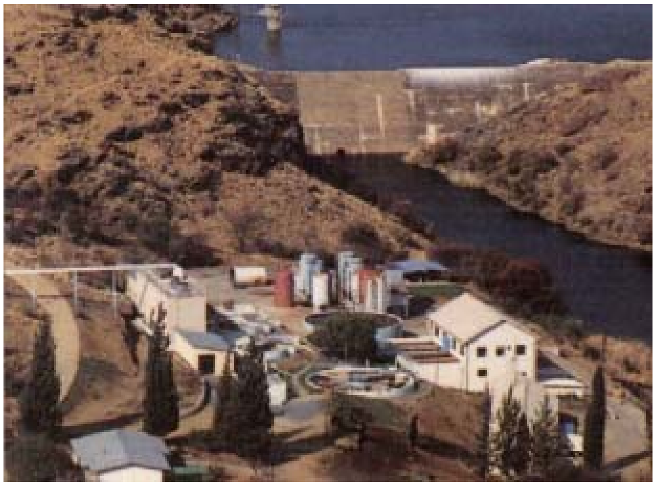
In Morocco, nearly 70 percent of all of the wastewater treatment plants are not functioning due to lack of spare parts and poor cost recovery. The Drarga project included several cost recovery features. The plant itself generates a number of products that have a market value: reclaimed water sold to farmers, reeds which are harvested and sold twice a year, dried sludge from the anaerobic basins mixed with organic wastes from Drarga to produce compost, and methane gas from the anaerobic basins, which is recovered and used to run pumps at the plant, thereby reducing electricity costs.

The plant has been operating continuously since October 2000 and has exceeded removal rate targets for the abatement of key pollution parameters such as BOD_5, nitrates, fecal coliforms, and parasites. **Table 8-15** summarizes the plant's performance.

The treated wastewater fulfills the requirements of WHO reuse guidelines, and therefore, is suitable for reuse in agriculture without restriction. The WRS project encouraged farmers to use reclaimed water for crop irrigation by developing demonstration plots using drip irrigation. Crops irrigated with reclaimed water in the demonstrations plots include cereals (wheat and maize), vegetables (tomatoes and zucchini), and forage crops (alfalfa and rye-grasses).

8.5.20 Namibia

Windhoek, the capital of Namibia, has a population of 200,000 and is located in the desert. In 1960, low rainfall (below 300 mm/year or 11.8 inches/year) caused the necessary water supply to fall short of the water demand. To meet this need, the country's water supply master plan included the long distance transport of 80 percent of its water supply from the Eastern National Water Carrier, extensive aquifer withdrawals from around the city, the development of a local surface reservoir, and the construction of a reclamation plant. The Windhoek reclamation plant has been In operation since 1968 with an initial production rate of 4800 m^3/d (1.3 mgd) (see photo) This operation is the only existing example of direct potable water production. The plant has since been upgraded in stages to its present capacity of 21,000 m^3/d (5.5 mgd).



The Goreangab Dam, adjacent to the Windhoek reclamation plant in Windhoek, Namibia. Photo courtesy of Valentina Lazarova

The wastewater from residential and commercial settings is treated in the Gammans treatment plants by trickling filters (6000 m^3/d or 1.6 mgd capacity) and activated sludge (12,000 m^3/d or 3.2 mgd capacity), with enhanced phosphorus removal. The effluents from each of these processes go to 2 separate maturation ponds for 4 to 12 days of polishing. Only the polished effluent from the activated sludge system is directed to the Windhoek reclamation facility as well as water from the Goreangab Dam (blending ratio 1:3.5), where it is treated to drinking water standards. After tertiary treatment, reclaimed water is blended again with bulk water from different sources.

Advanced treatment processes (including ozonation and activated carbon) have been added to the initial separation processes of dissolved air flotation, sedimentation, and rapid sand filtration. A chlorine residual of 2 mg/l is provided in distribution systems. Membrane treatment has been considered, as well as an additional 140 days storage of the secondary effluent from the maturation ponds in the Goreangab Dam.

Risk studies and evaluations of toxicity and carcinogenity have demonstrated that reclaimed water produced at the Windhoek facility is a safe and acceptable alternative water resource for potable purposes. Treatment capacity at the Windhoek treatment plant is currently being increased to 40,000 m^3/d (11 mgd).

8.5.21 Oman

Oman is another dry country with internal, renewable water resources estimated at 1 billion m^3/year (388 m^3/capita/

Table 8-15. Plant Performance Parameters at the Drarga Wastewater Treatment Plant

Parameter	Raw	Effluent	Reduction
BOD_5 (mg/l)	625	9	98.5%
COD (mg/l)	1825	75	95.8%
TSS (mg/l)	651	3.9	99.4%
NTK (mg/l)	317	10	96.8%
Fecal coliforms (per 100 ml)	1.6×10^7	500	99.99%
Parasites (Helminth eggs)	5	0	100%

year or 264 billion gallons/year). Surface water resources are scarce, with evaporation rates higher than annual rainfall. In 1995, total water withdrawals including depletion of non-renewable groundwater, were 1,223 Mm^3 (323,000 mg), of which 93.9 percent was used for agricultural purposes.

In 1995, the total produced wastewater was estimated at 58 Mm^3 (15,320 mg) (Food and Agriculture Organization of the United Nations, 2001), of which only 28 Mm^3 (7,400 mg) was treated and 26 Mm^3 (6,870 mg) was reused, mainly for irrigation of trees along the roads. The quantity of desalinated water produced in the same period was 34 Mm^3 (8,980 mg) and was used for domestic purposes. Since 1987, 90 percent of the treated effluent in the capital area has been reused for agricultural irrigation of tree plantations by drip irrigation.

About 262 wastewater treatment plants with capacities below 11,000 m^3/d (2.9 mgd) are currently in operation. Over 50 percent of these plants are located in the capital area around Muscat, with overall capacity of 52,000 m^3/d (13.7 mgd), and 20 percent are in Dhofar and Al-Batinat.

The largest wastewater treatment plants are Darsait, Al-Ansab, and Shatti al Qurm, which produce about 11,500 m^3/d (3 mgd), 5400 m^3/d (1.4 mgd), and 750 m^3/d (0.2 mgd), respectively. The plants use activated sludge processes with tertiary filtration and chlorination. Effluent is pumped to a storage tank that provides pressure to the water reuse transmission system.

There are 2 main Omani rules which regulate water reuse: (1) wastewater reuse, discharge and sludge disposal rules that include physico-chemical parameters such as suspended solids, conductivity, organic matters, heavy metals, etc., and (2) wastewater standards related to biological characteristics. Reuse regulations further classify wastewater use into 2 categories:

- Standard A - (200 FC/100 ml, less than 1 nematode ova/l) for irrigation of vegetables and fruit to be eaten raw, landscape areas with public access, controlled aquifer recharge, and spray irrigation

- Standard B - (1000 FC/100 ml, less than 1 nematode ova/l) for cooked vegetables, fodder, cereals, and areas with no public access

During the summer, all of the reclaimed water in the area is used, and demands are still not met. But during the winter, about 40 percent of the effluent from the Darsait plant is discharged through an outfall to the Gulf of Oman. In the future, the reuse network will be expanded so that all the effluent is reused for the irrigation of over 5,600 hectares (13,840 acres).

In the southern city of Salalah, the second largest city in Oman, an extensive wastewater collection, conveyance, treatment, and groundwater recharge project is nearing completion. The effluent from the 20,000-m^3/d (5.3-mgd) capacity tertiary treatment plant will be discharged to a series of gravity recharge wells along the coast of the Arabian Sea to form a saltwater intrusion barrier with additional wells further inland for replenishment of agricultural withdrawals.

8.5.22 Pakistan

The use of untreated wastewater for agricultural irrigation is common in Pakistan; a survey showed that it was practiced in 80 percent of all the towns and cities with populations over 10,000 inhabitants. The main crops cultivated on these lands are vegetables, fodder, and wheat. Vegetables and fodder are grown year-round to be sold at the local market, while wheat is grown in the winter season, mainly for domestic consumption. There are various reasons why untreated wastewater is used for irrigation such as: lack of access to other water sources, the high reliability of wastewater, the profits made by selling crops at the local market, and the nutrient value of the wastewater (reducing the need for fertilization). Farmers using untreated wastewater for irrigation bring in almost twice the income than farmers using normal irrigation water.

The City of Faisalabad has a population of over 2 million people, making it the third largest city in Pakistan. Located in the heart of the Punjab province, Faisalabad was founded in 1900 as an agricultural market town but since then has rapidly developed into a major agro-based industrial center. The local Water and Sanitation Agency (WASA) has identified over 150 different industrial divisions in the area, most of which are involved in cotton processing such as: washing, bleaching, dying, and weaving.

Lahore, Pakistan – Farmers installing a pump into a wastewater drain to draw water for irrigation. Source: International Water Management Institute

The use of wastewater for agricultural irrigation is common in Faisalabad. At least 9 different areas are irrigated with wastewater ranging in size from a few hectares to almost 1,000 hectares (2,470 acres). In total, over 2,000 hectares (4,940 acres) of agricultural land are irrigated with untreated wastewater in Faisalabad. The 2 main sites in Faisalabad are the Narwala Road site and the Channel 4 site. At Narwala Road, the wastewater is primarily of domestic origin while at the Channel 4 site the farmers use a mixture of industrial and domestic wastewater. One wastewater treatment plant in Faisalabad treats approximately 15 percent of the city's wastewater.

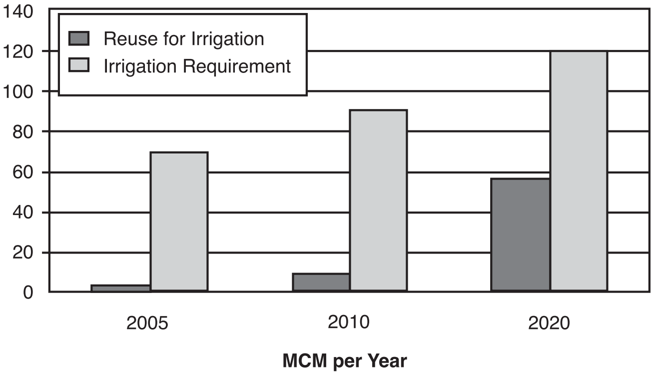
All wastewater reused in Faisalabad is used untreated. Farmers opt to use untreated wastewater over treated wastewater because it is considered to be more nutrient-rich and less saline than treated wastewater. In Faisalabad, like in many other cities in Pakistan, the local water and sanitation agency sells the wastewater to groups, or a community of farmers. The total revenue generated is mainly used for the operation and maintenance of the drinking water supply and sewage disposal systems.

The only wastewater that is currently not auctioned off is the wastewater at the Channel 4 site. The farmers at this site complain that the toxicity of the wastewater has diminished their choice in crops and forced them to use wastewater only in combination with brackish groundwater. The majority of the farmers at the Channel 4 site would prefer to use regular irrigation water (potable water), but increased water shortages in Pakistan have resulted in such low water allocations that the cultivation of crops without wastewater is no longer possible.

8.5.23 Palestinian National Authority

Currently, wastewater collection and treatment practices in the Palestinian National Authority (West Bank and Gaza Strip) are relatively low. Hence, the ability to reclaim and reuse the large volumes of wastewater generated in this highly water-deficient region is restricted. However, this situation is changing rapidly. International development aid from European countries and the U.S. is gradually strengthening the country's sanitation infrastructure, leading to the potential availability of greater volumes of reclaimed water in future years. In addition, several pilot projects have been conducted with varying results, but each project has demonstrated potential use for reclaimed water. The Ministries of Agriculture and Public Health have studied the use of reclaimed water in agriculture, landscape, industry, and groundwater recharge. As a result, the volume of reclaimed water use in Palestine is anticipated to grow over the next 20 years (**Figure 8-4**). Farmer acceptance of reclaimed water use

Figure 8-4. Future Demand for Irrigation Water Compared with Potential Availability of Reclaimed Water for Irrigation in the West Bank, Palestine



Source: Adapted from Abdo, 2001.

is relatively high, as measured in interviews with growers in both parts of the country (Abdo, 2001). Researchers found that, "the acceptance of farmers to use reclaimed water was conditional by securing water quality and getting governmental approval" (Abdo, 2001).

8.5.24 Peru

Peru is another Latin American country with serious water shortage problems. Half of the total population of 22 million live in the coastal region with an arid climate. The uneven distribution of water resources (very high inland, very short on the coast) contributes to the low water supply and sanitation coverage of the population of only 42 percent and 43 percent, respectively. Only 5 percent of the sewage in Peru is treated before discharge, mostly by stabilization ponds.

The reuse of predominantly raw sewage has been practiced for agricultural irrigation of vegetables, fodder, forest trees, cotton, and other crops. In Lima, about 5,000 hectares (12,000 acres) are irrigated with raw wastewater. A project is under development to irrigate about 4000 hectares (10,000 acres) near San Bartolo, south of Lima, with disinfected effluent from a lagoon system, including maturation ponds. Ica, located 300 kilometers (180 miles) south of Lima, uses effluent treated in facultative lagoons for restricted irrigation of 400 hectares (1,000 acres). At Tacna, Peru's southernmost town, effluent treated in lagoons is used to irrigate 210 hectares (500 acres) of land.

Peru uses raw sewage to irrigate market vegetables to be eaten without processing. This is typical of numerous cities in developing countries (Yanez, 1992). Furthermore, the effluent produced by stabilization ponds throughout Peru is of generally low quality because of design deficiencies, operational problems, or overloading. Numerous enteric bacterial and viral infections are reported, although the many possible transmission routes preclude attributing a direct link to irrigation practices (Strauss and Blumenthal, 1990).

8.5.25 Saudi Arabia

Water is a scarce and extremely valuable resource in Saudi Arabia. The renewable water resources are only 111 m^3/capita/year (2.4 billion m^3/year or 634 billion gallons/year). As a result of agricultural, urban, and industrial growth, the country's water demand has been increasing steadily over the past 2 decades, reaching around 20 billion m^3/year (5,283 billion gallons/year) in 2000. Irrigation consumes the largest amount of water in the kingdom. The majority of water consumption is supplied by depleting non-renewable groundwater and desalination. Saudi Arabia is now the world's largest producer of desalinated water, which covers 70 percent of the total water demand.

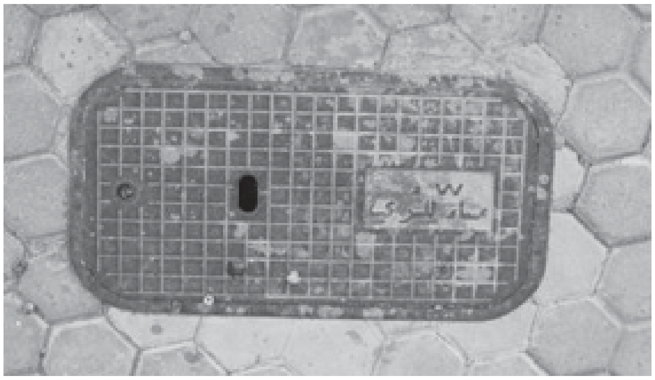
In 1985, Saudi Arabia began focusing on ways to economize and regulate the use of water through a National Water Plan. The plan provides for conservation, greater coordination between agriculture and water policies, intensive use of reclaimed waste and surface water, and better coordination of supply and distribution. As a result, Saudi Arabia is committed to a policy of complete water reuse.

Treated urban wastewater is considered a viable alternative resource for meeting water needs. It is estimated that approximately 40 percent of the water used for domestic purposes in urban areas could be recycled. In 1992, there were 22 sewage treatment plants in operation (stabilization ponds and activated sludge processes) with a total treatment capacity of 1.2 Mm^3/d (317 mgd). In 1992, 217 Mm^3 (57,300 mg) of treated wastewater were reused. Regulations require secondary treatment with tertiary treatment for unrestricted irrigation, with standards shown in **Table 8-16.**

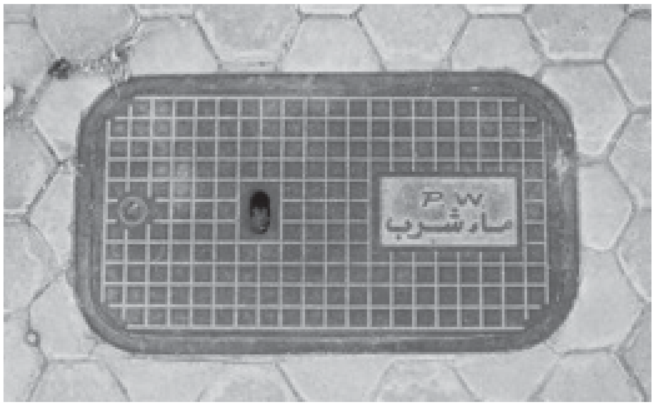
The largest water reuse scheme is in Riyadh. The most sophisticated Riyadh North treatment plant started operation at the beginning of 1994 ,with a design capacity of 200,000 m^3/d (53 mgd). Treatment at the Riyadh North plant includes a nitrification-denitrification activated sludge process with sand filtration for tertiary treatment. On the basis of this plant's treatment experience, the Riyadh Region Water and Sewerage Authority recently adopted a policy of treating all sewage to the tertiary level to comply with the current effluent guideline standards for unrestricted agricultural reuse enforced by the Ministry of Agriculture and Water. In 2000, an average daily flow of 415,000 m^3/d (110 mgd) of tertiary treated and disinfected effluent was available to potential users free of charge (see photos). However, only about 45 percent (185,000 m^3/d or 49 mgd) of this effluent has been reclaimed, predominantly for agricultural irrigation (170,000 m^3/d or 45 mgd), and about 15,000 m^3/d (4 mgd) is used for industrial cooling purpose by the Riyadh refinery. The remaining effluent is discharged to Wadi Hanifah, where it is mixed with the natural flow of the channel. Private sector farmers can extract some of this flow for irrigation.

In Jeddah, a 38,000-m^3/d (10-mgd) activated sludge facility was designed to produce high-quality reuse water to standards similar to drinking water standards. Advanced treatment includes reverse-osmosis, desalination, filtration, and disinfection. Other plants are planned for Jeddah and Mecca. In both cities, the reclaimed water will be used for municipal, industrial, and agricultural reuse. The City of Jubail is planning to have 114,000 m^3/

d (30 mgd) of reclaimed water for nonpotable industrial, urban landscaping, and other purposes.



Reclaimed water valve access box on sidewalk on Embassy Row in Riyadh, Saudi Arabia. Photo courtesy of Bahman Sheikh



Potable water valve access box on sidewalk on Embassy Row in Riyadh, Saudi Arabia. Photo courtesy of Bahman Sheikh

A recent master planning effort studied the infrastructure needed to meet Riyadh's expected growth of an additional 7 million inhabitants by 2021 (over and above the current 3.5 million). The master plan recommended 12 satellite water reclamation plants be constructed (Sheikh and Aldu Kair, 2000). Each plant would treat wastewater from a district and return the reclaimed water (disinfected tertiary effluent) for irrigation of residential gardens, public parks, and other landscaping, in addition to industrial and commercial uses in various parts of the city. The water reuse component of the integrated water cycle system is expected to have an ultimate capacity of 1.5 Mm^3/d (400 mgd).

8.5.26 Singapore

Singapore is a city-state with a dense, growing population of almost 4 million people. Although the island receives heavy rainfall averaging 250 cm/year (100 inches/year), it has limited water resources because of its small size (680 square kilometers or 265 square miles). The island is fully served by a comprehensive wastewater infrastructure - 6 secondary (activated sludge) treatment plants discharge wastewater effluent to the sea.

Since February 2003, Singapore has been supplying high quality reclaimed water (meeting drinking water standards), called "NEWater", directly to industries and commercial and office buildings for process and other nonpotable uses such as air conditioning and cooling. The goal is to supply 245,000 m^3/d (64.5 mgd) of NEWater for nonpotable use by year 2011.

Table 8-16. Reclaimed Water Standards for Unrestricted Irrigation in Saudi Arabia

Parameter [(a)]	Maximum Contaminant Level
BOD	10
TSS	10
pH	6 – 8.4
Coliform (count/100 ml)	2.2
Turbidity (NTU)	1
Aluminum	5
Arsenic	0.1
Beryllium	0.1
Boron	0.5
Cadmium	0.01
Chloride	280
Chromium	0.1
Cobalt	0.05
Copper	0.4
Cyanide	0.05
Fluoride	2
Iron	5
Lead	0.1
Lithium	0.07
Manganese	0.2
Mercury	0.001
Molybdenum	0.01
Nickel	0.02
Nitrate	10
Selenium	0.02
Zinc	4
Oil & Grease	Absent
Phenol	0.002

Note: (a) In mg/l unless otherwise specified

The NEWater is reclaimed from municipal wastewater using the most advanced technologies, including reverse-osmosis and UV disinfection. NEWater is also being used for indirect potable use. Since February 2003, about 9,000 m^3/d (2.4 mgd) of NEWater has been discharged into reservoirs and treated again in a conventional water treatment plant before introduction into the distribution system for domestic potable use. The amount of reclaimed water for indirect potable use will increase gradually by 4,500 m^3/d (1.2 mgd) yearly to 45,000 m^3/d (12 mgd) by 2011. Currently, 2 NEWater plants are in operation with a total production capacity of 72,000 m^3/d (19.5 mgd). The cost of NEWater production is estimated to be half the cost of desalinized seawater.

Reclaimed water of lower quality than NEWater has been supplied to industries in the western part of Singapore since the 1960s. Industrial reclaimed water treatment involves conventional sand filtration and chlorination before it is pumped to a service reservoir for distribution to the industries. The current demand for industrial water is about 90,000 m^3/d (24 mgd).

8.5.27 South Africa

Limited water resources with uneven distribution, highly variable rainfall, repetitive, severe water shortages, and intensive industrial and urban development are the main factors impacting the need for water reuse in South Africa. In 1996, the population was at 38 million, of which 55.4 percent lived in urban regions. The population growth rate is estimated to be 2.4 percent per year. Based on these population figures, the water demand is expected to double in the next 30 years. In fact, projections indicate that the water demand will exceed available water resources soon after the year 2020.

Water reuse is considered a very promising alternative water resource. Over 1,000 wastewater treatment plants are in operation with biological nitrogen removal as the predominant treatment technology. However, according to Grobicki (2000), less than 3 percent of the available treated wastewater is being reused (an estimated volume of 41 Mm^3/year or 11,000 mg/year).

Aquifer recharge and industrial uses are currently the major water reuse applications. One of the country's larger reuse projects is in Durban (3 million inhabitants) where reclaimed municipal wastewater from the Southern wastewater treatment facility is used by the paper industry and petrol refineries. The tertiary treatment of the secondary effluent from the Southern wastewater treatment works consists of coagulation/flocculation with lamella settling, dual media filtration, ozonation, activated carbon, and chlorination. The reclaimed capacity is 47,000 m^3/d (12.4 mgd).

The largest aquifer storage and recharge project is in the Atlantis area (70,000 people), situated 50 kilometers (31 miles) north of Cape Town. Two infiltration basins augment the aquifer storage capacity with 4,500 m^3/d (2 Mm^3/year or 1.2 mgd) of treated wastewater. High-quality stormwater is also discharged to another aquifer. This water is subsequently abstracted after an underground residence time of about 1 year as part of a 15,000-m^3/d (4.0-mgd) groundwater supply project. In addition, treated industrial wastewater is used as a barrier against saltwater intrusion near the coast. A number of small recharge systems exist where farmers augment groundwater supply through small, earth-dams.

In addition to industrial reuse and aquifer recharge, a number of small water reuse irrigation systems are currently in place in the areas of Durban and Cape Town, mostly for landscape irrigation at golf courses (King David, Mowbray, Rondebosch, Milnerton, Steenberg, Parow, Durbanville, Cato Ridge, Langebann Country Club), sport facilities (Milnerton Racecourse, Milnerton Beachfront, Bellville South, Kraaifontein Sportsdround, Peninsula Technion, etc.), and various agricultural applications.

Since many of the country's water bodies provide little dilution capacity, there has been significant focus on water reuse initiatives involving planned indirect reuse through discharge to surface bodies. The return of treated wastewater to rivers in inland areas of South Africa has been considered an important aspect of water management. Despite the deterioration of surface water quality, the well-established, intensive, potable treatment system (86 percent water supply coverage) minimizes any potential health risk. This indirect potable reuse via surface flow augmentation accounts for several million cubic meters per day. In fact, with increasing water demand, the volume of return flows is increasing steadily and will be greater than natural run-off in a number of regions by 2020. For example, in the Gauteng area (Johannesburg-Pretoria metropolis), 60 percent of the surface water used for water supply is treated wastewater. The Hartebeespoort Dam, used to supply water to Johannesburg (10 million people), receives 50 percent of its volume from wastewater effluent. In addition to this indirect potable reuse, the effluent from Johannesburg Northern Works (200,000 m^3/d or 52.8 mgd) is also used by a power station and for the irrigation of 22,000 hectares (54,400 acres) of industrial crops.

The implementation of the National Water Act of 1997 resulted in the establishment of catchment management authorities. These authorities are helping to focus the country's water resources management enhancement. One of the major tasks of these catchment agencies will be the management of environmental compliance, while water supply and sanitation will remain the responsibility of local governments and municipalities. Effluent and environmental standards specification and enforcement are the duties of the central government, in particular the Department of Water Affairs and Forestry.

Water reuse standards are currently being revised. Existing regulations apply very stringent drinking water standard requirements for water to be used for human washing and irrigation of food crops to be eaten raw. Tertiary treatment with no fecal coliforms is required for unrestricted irrigation of sport fields, pasture for milking animals, and toilet flushing. The microbiological limits have been relaxed for discharge into river systems to 126 FC/100 ml, or sometimes even higher. The unrestricted irrigation and irrigation of non-food crops requires less that 1000 FC/100 ml.

8.5.28 Spain

Although both planned and incidental water reuse have been taking place in Spain for decades, particularly in coastal Mediterranean areas and in the Balearic and Canary inlands, planned water reuse became a viable option as a consequence of the First International Symposium on Water Reclamation and Reuse held in Costa Brava in 1991 (IAWPRC, 1991). Since then, numerous projects have been implemented across the country, mainly serving agricultural irrigation as well as landscape irrigation, environmental restoration, and urban uses such as street cleaning, urban landscape irrigation, boat washing, and fire control.

The major impetus for water reclamation and reuse has been based on the viable alternatives for cost recovery. The highly competitive water markets of the Canary Islands, the highly productive hydroponic crops of the southern Mediterranean coast, and the more recent demands for golf course irrigation, have largely contributed to the expansion of water reclamation and reuse in Spain. Farmers have begun to realize the considerable benefits from a reliable supply of good quality water, particularly during the summer season, when water shortages are most common.

The Water and Sanitation District of Costa Brava (located in the north of Barcelona) has been one of the leading agencies in developing water reuse alternatives for the last 15 years. As secondary wastewater treatment becomes a standard in most urban and rural areas, a renewed interest has developed to reclaim and reuse treated effluent, particularly in coastal areas, where tourism, environmental protection, and intensive agriculture have become top priorities. Mediterranean coastal cities, like Barcelona and Valencia, with traditional high levels of incidental reuse in agriculture, are seriously considering rehabilitation and expansion of their treatment facilities, as to satisfy the water quality requirements associated with environmental and public health protection, and include adopting microbiological quality levels that are nearly comparable to those of drinking water quality.

In 1999, the Spanish Ministry of Public Works, Transportation and Environment proposed a set of physicochemical and microbiological standards for 14 possible applications of reclaimed water. The proposed microbiological standards range from limits similar to those included in the Title 22 regulations (Californian reuse standards), for unrestricted water uses, to limits similar to those included in the WHO guidelines, where public exposure to reclaimed water is restricted. Several regional governments have adopted and are currently considering either or both of the above criteria and guidelines as a practical way to regulate and promote water reclamation and reuse.

8.5.28.1 Costa Brava, Spain

The Consorci de la Costa Brava (CCB, Costa Brava Water Agency) is a public organization, created in 1971, that deals with the management of the water cycle (wholesale purveyor of drinking water, wastewater treatment, and water reuse) in the 27 coastal municipalities of the Girona province. In Spain, CCB is considered to be a pioneer organization in the management of the water cycle. The CCB embraces biological secondary treatment of wastewater when the main option in coastal areas has been disposal into the sea through submarine outfalls. The CCB introduced the concept of planned water reuse in the late 1980s.

The CCB opted for the progressive development of this resource after a conference in 1985, where renowned specialists presented planned wastewater reclamation and reuse systems in the U.S. Being that Costa Brava itself is an area with a Mediterranean climate and periodic periods of drought, it became clear to the governing board of the CCB that treated wastewater should be considered as a resource to be developed rather than to be disposed. Despite the lack of regulations in Spain, the CCB proceeded to develop water reuse while maintaining public health. Reclaimed water initially was disinfected secondary effluent; continuing improvements to water reclamation facilities have led facilities to evolve into Title 22 reclamation treatment trains, consisting of coagulation, flocculation, sedimentation, filtration, and disinfection. The major leap forward in wastewater reclamation and reuse occurred in 1996, when several water reuse projects were approved and partially (80 percent) funded by the European Union (EU).

8.5.28.2 Portbou, Spain

The municipality of Portbou (Girona, Spain - population 1,600) is located in a remote area in northern Costa Brava, in the midst of a very mountainous area and facing the Mediterranean Sea. A small reservoir, located on the mountains on the western city limits, with a capacity of 130,000 m^3 (34.3 mg), supplies potable water to the area. The maximum drinking water demand is 160,000 m^3/year (42.3 mg/year) and the potable water supply is extremely dependent on rainfall (annual average 550 mm or 21.7 inches). There are no wells to supplement potable water supply, so the drought conditions of the period 1998 through 2001 resulted in water restrictions for nonpotable water uses including landscape irrigation. The municipality has a 360-m^3/d (95,000-gallons/d) treatment facility which includes coagulation, flocculation, direct filtration, and a UV-chlorine combined disinfection system to provide reclaimed water for a variety of urban nonpotable water uses such as: landscape irrigation, street cleaning, and fire protection. The municipality is also installing a pipeline to deliver high-quality reclaimed water for boat cleaning to a nearby marina.

8.5.28.3 Aiguamolls de l'Empordà Natural Preserve, Spain

The Aiguamolls de l'Empordà Natural Preserve (AENP) is a marsh located in Northern Costa Brava between the mouths of the Muga and Fluvià rivers. This naturally occurring marsh formed as a result of the periodical floods from both rivers, producing a rich and diverse environment, ranging from saline to freshwater ecosystems. The construction of the Boadella dam in the upper Muga River in the late 1960s and urbanization in coastal areas dramatically changed the river flow and affected the marshes, which were finally declared a natural preserve in 1984. A visitor center was created and with it an 18-hectare (44.5-acre) manmade lagoon (Cortalet lagoon), which is artificially fed by the Corredor stream from autumn to late spring. In summer both this stream and the lagoon usually dry out.

In 1995, the CCB received funding from the EU to construct a 7-hectare (17.3-acre) wetlands treatment system to reduce the nitrogen content in the secondary effluent from the Empuriabrava wastewater treatment plant, which includes extended aeration and polishing lagoons. The effluent is then reused for environmental purposes at the Cortalet lagoon. The system came into operation in 1998. Since then, 500 to 550 m^3/year (132,000 to 145,300 gallons/year) of denitrified reclaimed water have been pumped to the Cortalet lagoon, preventing its summer desiccation. Apart from this, the constructed wetland itself has become a great waterfowl attraction and is one of the favorite spots in the natural preserve for bird watching. Since the Empuriabrava community uses water from the Boadella reservoir as a potable water supply, this project returns to the AENP a portion of the flows that are naturally used to feed these marshes, thus creating a true restoration of the original habitat.

8.5.28.4 The City of Vitoria, Spain

Water reclamation and reuse has been the final step of an ambitious integrated water resources management program for the City of Vitoria (250,000 people, located in the Basque Country, northern Spain) that began in 1995. The enthusiasm and determination of the most directly affected stakeholders, the agricultural community, to promote and fund the design, construction, and OM&R of the wastewater reclamation and reuse facilities have been the driving factors for the practical implementation of this far-reaching program.

The water reclamation and reuse project includes a wastewater reclamation facility, with a capacity of 35,000 m^3/d (9.2 mgd) and an elaborate pumping, conveyance, and storage system, satisfies water quality requirements specified by Title 22 of the California Code of Regulations. The project objectives were: (1) to provide water for spray irrigation of 9,500 hectares (23,000 acres) during the summer, (2) to pump about 0.5 m^3/s (12,000 gallons/d) of reclaimed water to reservoirs, and (3) to store reclaimed water in a 6,800-m^3 (1.8-mg) reservoir for agricultural irrigation.

8.5.29 Sweden

As in other Scandinavian countries, Sweden has relatively high freshwater availability and the annual water withdrawal represents only 2 percent of the renewable water resources, 352 m^3/capita/year (93,000 gallons/capita/year) in 1997 (Angelakis *et al.,* 2001). Industry is characterized by higher water demand at 55 percent, compared to 36 and 9 percent for urban uses and agriculture, respectively.

Advanced sewage treatment, including carbon and phosphorus removal, is common practice in Sweden. The upgrading of many wastewater treatment plants for nitrogen removal has been implemented over the past years, especially in the coastal region up to the archipelago of Stockholm.

Over 40 irrigation projects have been constructed in water-scarce areas in the southeast region, where wastewater is collected in large reservoirs and stored for up to 9 months before being used for irrigation with or without blending with surface water. Agricultural demands for water in these areas are intense, as the precipitation is small. Two main benefits of these projects have been reported: (1) additional wastewater treatment in a safe and financially attractive way, including recycling of nutrients, and (2) the creation of alternative water resources for agricultural irrigation which allow groundwater resources to be dedicated for other purposes. After approximately 10 years, only positive impacts have been reported for these water reuse projects. After a minimum of 4 months storage, the water quality is adequate for swimming according to the Swedish legislation. Subsequently, there have been no sanitary problems related to water reuse.

A new environmental act in Sweden requires nitrogen reduction for most of the large wastewater treatment plants. This act may encourage future development of these water reuse irrigation systems. The increasingly stringent environmental requirements on the discharge of industrial wastewater promote byproduct recovery and industrial wastewater reclamation. Significant research and development efforts have been made on the use of membrane technologies, including industrial desalination for zero discharge.

8.5.30 Syria

In Syria, agriculture is an important economic sector. In addition to the role it plays in enhancing food security, it accounts for 60 percent of the national revenue from non-oil exports (Food and Agriculture Organization of the United Nations, 2001). The agricultural sector employs over 27 percent of the total manpower in the country. In view of the harsh climatic conditions, irrigation is given a high priority as a means to boost agricultural production and to ensure a high level of food security. The total irrigated area in Syria is in the range of 1.2 million hectares (3 million acres), with 61 percent of the water coming from groundwater and the rest from surface water sources.

Until recently, the amount of municipal wastewater was small because of the limited population in cities. Most of these waters were not reused because of their lack of quality and the availability of good quality water for irrigation. With an increase in urban population and the spread of drinking water supply connections, particularly in large cities, the volume of municipal wastewaters has increased rapidly. In fact, the volume of wastewater in Syria was estimated at 451, 650 and 1,642 Mm^3/year (365,000, 527,000, and 1,330,000 acre-feet/year or 119,000, 172,000 and 434,000 mg/year), respectively for 1995, 2000, and 2025. At the same time, the availability of good quality water has diminished around cities. This has led farmers to start using untreated wastewater. However, this wastewater is generally mixed with good quality water and is used essentially, but not exclusively, for irrigating trees and forage crops (Food and Agriculture Organization of the United Nations, 2001).

Table 8-17 shows the status of wastewater treatments in various Syrian cities. Collected raw sewage from the cities (except for a part of Damascus), villages, and other residential areas where sewage systems are in operation, is used without any treatment. The wastewater is used either for direct irrigation of agricultural crops or, if not disposed to the sea, it is discharged into water bodies which are then used for unrestricted irrigation (Food and Agriculture Organization of the United Nations, 2001).

8.5.31 Tunisia

Situated in an arid and semi-arid area, Tunisia is facing increasingly serious water shortage problems (Bahri, 2000). In 2000, water availability was 440 m^3/capita/year (116,200 gallons/capita/year) with withdrawals accounting for 78 percent of the renewable resources. These water deficits are projected to increase with population growth, an increase in living standards, and accelerated urbanization. According to recent forecasts, increased domestic and industrial water consumption by the year 2020 may cause a decrease in the volume of fresh water available for Tunisian agriculture. Moreover, water shortage problems are associated with increasing environmental pollution. To help address this situation, different mobilization infrastructures (dams, hillside-dams and lakes, recharge and floodwater diversion structures, wells) are under construction. Water transfer systems have been implemented and existing reservoirs have been integrated into a complex hydraulic system, allowing interregional transfer and spatial redistribution of water.

Most residents of large urban centers have access to various, adequate sanitation systems and wastewater treatment facilities (78 percent versus 61 percent for all of the population and 40 percent in rural areas). Of the 240 Mm^3 (63,400 mg) of wastewater discharged annually, 156 Mm^3 (41,200 mg) is treated at 61 treatment plants. Five treatment plants are located in the Tunis area, producing about 62 Mm^3/year (16,400 mg/year), or 54 percent of the country's treated effluent. As a rule, municipal wastewater is treated biologically, mainly in oxidation ditches, activated sludge processes, and stabilization ponds. Sanitation master plans have been designed for several towns. Most existing reuse programs were implemented and integrated into the scheme of al-

Table 8-17. Wastewater Treatment Plants in the Cities of Syria

City	Wastewater Flow		Status in Year 2000
	m^3/day	mgd	
Damascus	485,000	128	In Operation
Salamieh	5,800	2	In Operation
Aleppo	255,000	67	Under Implementation
Hama	70,000	18	Under Implementation
Homes	134,000	35	In Operation
Dar's	21,800	6	Studied, Ready for Implementation
Al-Swaida	18,750	5	Studied, Ready for Implementation
Idleb	30,000	8	Studied, Ready for Implementation
Lattakia	100,830	27	Invitation of Offers for Implementation
Tatous	33,450	9	Invitation of Offers for Implementation
Total	1,154,630	305	---

Source: Sa'dulla Al Shawaf, Ministry of Irrigation, Syria, 2000.

ready existing treatment plants. However, for new plants, treatment and reuse needs are combined and considered during the planning stage.

Although some pilot projects have been launched or are under study for groundwater recharge, irrigation of forests and highways, and wetlands development - the wastewater reuse policy, launched in the early 1980s favors planned water reuse for agricultural and landscape irrigation (Bahri, 2000). Approximately 7 to 10 percent of the overall irrigated area (14,500 hectares or 35,830 acres) is located around the Great Tunis. Reclaimed water is used mainly during spring and summer, either exclusively or as a complement to groundwater. About 35 Mm^3 (9,250 mg) of reclaimed water annually is allocated for irrigation. In some areas, irrigation with effluent is well established and most of the volume allocated is being used. In new areas, where irrigation is just beginning, the reclaimed water usage rate is slowly increasing. The annual volume of reclaimed water is expected to reach 290 Mm^3 (76,600 mg) in the year 2020. At that point, reclaimed water could be used to replace groundwater (18 percent) that is currently being used for irrigation, particularly in areas where excessive groundwater mining is causing seawater intrusion in coastal aquifers.

The area currently irrigated with reclaimed water is about 7,000 hectares (17,300 acres), 80 percent of which is located around Tunis, with a few other locations near Hammamet, Sousse, Monastir, Sfax, and Kairouan. By 2020, the area irrigated with reclaimed water is planned to expand between 20,000 and 30,000 hectares (49,400 and 74,100 acres). However, the availability of agricultural land is a limiting factor, especially along seashores where most of the reclaimed water is generated. The most common irrigation methods are sprinklers (57 percent of the equipped area) and surface irrigation (43 percent). Another common water reuse practice is golf course irrigation. In fact, 8 existing golf courses are irrigated with treated effluent in compliance with the WHO guidelines (1989) for water reuse on recreational areas with free access to the public (2.3 log units /100 ml) during winter and part of spring.

Water reuse in agriculture is regulated by the 1975 Water Law and by the JORT Decree No. 89-1047 (1989). The reclaimed water quality criteria for agricultural reuse were developed using the guidelines of Food and Agriculture Organization of the United Nations (1985) and WHO (1989) for restricted irrigation (less than 1 helminth egg/l), and other Tunisian standards related to irrigation or water supply. The Water Law prohibits both the use of raw wastewater in agriculture and the irrigation with reclaimed water of any vegetable to be eaten raw. The 1989 decree specifically regulates reuse of wastewater in agriculture and allows the use of secondary treated effluent for growing all types of crops except vegetables, whether eaten raw or cooked. The main crops irrigated with treated wastewater are fruit trees (citrus, grapes, olives, peaches, pears, apples, and grenades), fodder (alfalfa, sorghum, and berseem), sugar beet, and cereals. Peri-urban irrigated areas are mainly devoted to the production of vegetables eaten raw, which is a major constraint to reuse development because of the crop-type irrigation restrictions. Specifications regarding the terms and general conditions of reclaimed water reuse (and the precautions that must be taken in order to prevent any contamination to workers, residential areas, and consumers) have also been established.

Two new, large water reuse projects are planned for Tunis West and the Medjerda catchment area. The new wastewater treatment plant for the City of Tunis West will have a design capacity of 105,000 m^3/d (41 Mm^3/year or 27.7 mgd) by the year 2016, which will enable the irrigation of approximately 6,000 hectares (14,800 acres). The ongoing Medjerda catchment area sanitation program is planning to equip the 11 largest towns with sewage networks, treatment plants, and reclaimed water irrigation schemes in order to protect natural resources, particularly the Sidi Salem dam (450 Mm^3 or 119,000 mg), from contamination by raw wastewater.

The National Sewerage and Sanitation Agency is responsible for the construction and operation of all sewage and treatment infrastructure in the larger cities of Tunisia. When effluent is to be used for agricultural irrigation, the Ministry of Agriculture is responsible for execution of the projects, which include the construction and operation of all facilities for pumping, storing, and distributing the reclaimed water. Various departments of the Ministry are responsible for several functions, while regional departments supervise the Water Code and collection of charges, about \$0.01/m^3 (\$0.04/1,000 gallons), according to the World Bank (2001).

8.5.32 United Arab Emirates

The United Arab Emirates (UAE) is a federation of 7 emirates: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Umm ul Quwain, and Ajman. According to the 1995 national census of the Ministry of Planning, the population is approximately 2.4 million, mostly urban (83 percent). Only a few renewable water resources are available - 200 Mm^3 or 61 m^3/capita/year (52,830 mg or 16,100 gallons/capita/year) in 2000. The annual water demand of 954 m^3/capita/year is met by depleting non-renewable aquifers and desalinization (700 Mm^3/year or 185,000 mg/year in 1997). It is estimated that about 500 Mm^3 (132,000 mg) of wastewater were produced in the urban areas during 1995, of which 108 Mm^3 (28,530 mg) were treated and reused (Food and Agriculture Organization of the United Nations, 2002).

By far the largest emirate in the United Arab Emirates is Abu Dhabi, where extensive nonpotable reuse has been practiced since 1976. The system, designed for 190,000 m^3/d (50 mgd), includes a dual distribution network which uses reclaimed water—referred to, in the UAE and other Persian Gulf states as treated sewage effluent (TSE)—for urban irrigation of 15,000 hectares (38,000 acres) of urban forests, public gardens, trees, shrubs, and grassed areas along roadways. The treatment facility provides tertiary treatment with rapid sand filtration and disinfection by chlorination and ozonation. The reclaimed water distribution system is operated at lower pressure than the potable system to reduce wind spraying. Conveyance and control elements of the system are painted purple, marked, and labeled to avoid cross-connections.

Al-Ain, with a projected population of 250,000 by the year 2000, produces reclaimed water that may be used only for restricted irrigation. The reclaimed water is pumped about 12 kilometers (7 miles) outside the city where it is used for irrigation in designated areas. Treatment includes dual-media filtration and chlorination for disinfection.

8.5.33 United Kingdom

The impact of climatic change on inland water resources has been noted in the southeast of England in the United Kingdom, where a drought had been experienced in the early 1990s. As a result, diminishing raw water supplies led water planners to develop projects to help safeguard and optimize existing raw water supplies, as well as search for future resources.

The United Kingdom has used sewage effluents to maintain river flows (and ecosystems) and, through river abstractions, to contribute towards potable water and to augment other supplie. This practice is particularly developed for the major rivers in the south and east, including the Thames River, where it is not always feasible to abstract upstream of sewage works.

For example, in the Water Resource Plan for East Anglia of 1994, the National Rivers Authority (a predecessor body of the Environment Agency) recognized the importance of reclaiming wastewater effluents to augment the flow in the River Chelmer and the water stored in the Hanningfield reservoir in Essex, United Kingdom. As a result of this decision, the first indirect potable reuse project in Europe was implemented in 1997 (Lazarova, 2001). Water quality for this project has been strictly observed including the monitoring of viruses and estrogens, as well as numerous studies of the impact of reuse on the environment (estuary ecosystem) and public health (Walker, 2001). The project was developed in 2 stages. The first stage involved a temporary system to pretreat the effluent at Langford Works with UV disinfection before pumping the effluent to Hanningfield reservoir, a large 27-Mm^3, 354-hectare (7,130-mg, 875-acre) bankside raw water reservoir with a residence time of up to 214 days. Abstraction from the reservoir is followed with advanced potable water treatment at the Hanningfield

Treatment Works. The discharge consent applied for utilizing 30,000 m^3/d (7.9 mgd) of the sewage effluent in 1997 to 1998. The second stage of the project involves more traditional water reuse - discharging the effluent back into the river and improving the wastewater treatment at the source - Langford Treatment Works. This medium/long term plan was approved in 2000 and the new tertiary treatment plant has been in operation since the beginning of 2002. The reclaimed water is discharged into the River Chelmer and then abstracted along with river water 4 kilometers (2.5 miles) downstream at Langford Treatment Works for drinking water supply.

There are also some examples of direct treated wastewater reuse in the United Kingdom, mainly for irrigation purposes such as: golf courses, parks, road verges, as well as for commerce, car washes, cooling, fish farming , and industry (power station cooling, for example). One of the more recent projects "Waterwise," was started in January, 1999, to reuse the water from the Beazer Homes district. Wastewater from 500 individual houses is treated by a conventional process; then 70 percent of the water is then discharged to the river and the remaining 30 percent undergoes tertiary treatment before being redistributed to 130 houses connected to a dual distribution network as reuse water.

There are several pilot projects being conducted to study reusing grey water from washing machines, baths, and showers for the flushing of toilets. Since domestic use accounts for over 40 percent of the total water demand in the United Kingdom, 30 percent of which is used for toilet flushing, the interest in grey water reuse is growing. In some case, run-off water is also collected from the roofs of the houses, treated, and blended with grey water to be reused.

A large in-building water reuse project, known as "Watercycle," was implemented in 2000 at the Millennium Dome in London. The design capacity of the plant is 500 m^3/d (132,000 gallons/d). Run-off water, grey water, and polluted groundwater are treated in 3 different treatment trains to a high quality standard for reuse in the more than 600 toilets and over 200 urinals on-site.

8.5.34 Yemen

Yemen has a predominantly semi-arid to arid climate with a large rural population (76 percent). The annual renewable water resources were estimated in 2000 at 4.1 billion m^3 or 226 m^3/capita/year (1,083 billion gallons or 59,700 gallons/capita/year) (surface water and groundwater). There is an increasing awareness in Yemen of groundwater depletion.

The total amount of treated wastewater is estimated at around 92,000 m^3/d (24.3 mgd) from 9 treatment facilities. The largest plants are located in Sana's, Ta'aiz, Al-Hudeidah, and Aden. The common wastewater treatment method used is stabilization ponds, with the exception being the facility of Sana's, which utilizes an activated sludge system. In addition, 3 new treatment plants with stabilization ponds will be in operation in 2002 in Aden, Yarim, and Amran with design capacities of 60,000, 3,500, and 6,000 m^3/d (15.9, 0.93, and 1.6 mgd), respectively. New plants are also planned in Beit Al-faqih, Bagel, and Zabid.

Controlled water reuse for irrigation is practiced in the coastal plain cities (Aden, Hodeidah), mainly to build the green belts, as well as for the fixation of sand dunes or control of desertification in affected areas. Unplanned and unregulated wastewater reuse is commonly practiced by the farmers to grow corn and fodder in Taiz area, or to grow restricted and non-restricted crops, like vegetables and fruits, in the Sana'a area.

In 2000, the new wastewater treatment plant for the capital city of Sana'a began operation. The activated sludge treatment plant, with a design capacity of 50,000 m^3/d (13 mgd), faces numerous operational problems. The problems are due, among other things, to a lack of sufficient operational storage and an organic load of the incoming wastewater that is higher than the load used in the plant design. The plant substantially increased the amount of reclaimed water available to farmers in 15 villages along the wadi, downstream of the plant. Farmers pump the reclaimed water with their own pumps to their fields. This has reduced the pressure on the overexploited aquifer in the area. The number of active agricultural wells was reduced from 80 to 55, mainly because pumping reclaimed water is cheaper than operating the wells. Vegetables are the main crops grown and there are no crop restrictions. Farmers have little information about the quality of the treated wastewater. Upgrades to the treatment plant are planned to make the reuse of reclaimed water safer in the future (World Bank, 2001).

Five water reuse projects are being initiated in Aden, Amran, Hajjah, Ibb, and Yarim. Funded by the German government's Kreditanstalt für Wiederaufbau (KfW), these projects will make significant volumes of secondary treated reclaimed water available, mostly for agricultural irrigation. In Aden, some of the water will be used for industrial cooling. The wastewater collection and treatment systems are already being constructed or have recently been completed for each of the cities in the program.

8.5.35 Zimbabwe

In Zimbabwe, water reuse is an established practice that has been accepted not only by engineers and environmentalists, but also by all stakeholders involved in the water resources management of the country (Hranova, 2000). This acceptance of water reuse has been influenced by 2 major factors governing the water resources systems management of the country: (1) the scarcity of available natural water resources, and (2) the watershed effect. Geographically, Zimbabwe's major towns lie on or close to the main watershed. Therefore, in order to increase the catchment yield, water supply dams are, in many cases, located downstream from the urban areas.

The present policy of wastewater management focuses primarily on 2 major types of water reuse. One is direct reuse of treated wastewater for irrigation purposes, where the treatment technologies adopted are based on classical biological treatment systems, mainly trickling filters, waste stabilization ponds, and combinations. The 2 largest direct reuse projects for irrigation purposes are located in 2 major towns of Zimbabwe – Harare and Bulawayo. The second type is indirect potable water reuse, where municipal wastewater is treated in biological nutrient removal plants and then discharged to watercourses and reservoirs that are used for potable water supply downstream from the discharge point.

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Appendix A

State Reuse Regulations and Guidelines

Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
Arizona	*Class A reclaimed water:* • Secondary treatment, filtration and disinfection • Chemical feed facilities required to add coagulants or polymers if necessary to meet turbidity criterion • Turbidity - 2 NTU (24 hour average) – 5 NTU (not to exceed at any time) • Fecal coliform - none detectable in 4 of last 7 daily samples - 23/100 ml (single sample maximum) *Class B reclaimed water:* • Secondary treatment and disinfection • Fecal coliform - 200/100 ml (not to exceed in 4 of the last 7 daily samples) - 800/100 ml	• Case-by-case basis			• Application rates based on either the water allotment assigned by the Arizona Department of Water Resources (a water balance that considers consumptive use of water by the crop, turf, or landscape vegetation) or an alternative approved method			• Class A reclaimed water may be used for residential landscape irrigation, schoolground landscape irrigation, toilet and urinal flushing, fire protection systems, commercial closed-loop air conditioning systems, vehicle and equipment washing, and snowmaking • Class B reclaimed water may be used for landscape impoundment, construction uses, and street cleaning • Application methods that reasonably preclude human contact with reclaimed water will be used when irrigating

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	(single sample maximum)							
Arkansas	- Secondary treatment and disinfection	- As required by regulatory agency		- Based on water balance using divisional average annual 90 percentile rainfall	- Hydraulic - 0.5 to 4.0 in/wk - Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l	- Required - One well upgradient - One well within site - One well down- gradient - More wells may be required on a case-by-case basis	- Determined on a case-by-case basis	
California	- Disinfected tertiary recycled water -oxidized, coagulated (not required if membrane filtration is used and/or turbidity requirements are met), filtered, disinfected - Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 240/100 ml (maximum any one sample)	- Total coliform - sampled at least once daily from the disinfected effluent - Turbidity - continuously sampled following filtration	- Warning alarms - Back-up power source - Multiple treatment units capable of treating entire flow with one unit not in operation or storage or disposal provisions - Emergency storage or disposal: short-term, 1 day; long-term, 20 days - Sufficient number of qualified personnel				- No irrigation within 50 feet of any domestic water supply well unless certain conditions are met	- Includes landscape irrigation of parks, playgrounds, schoolyards, residential lawns, and unrestricted access golf courses, as well as use in decorative fountains - Also allows reclaimed water use for toilet and urinal flushing, fire protection, construction uses, and commercial car washing

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	• Turbidity requirements for wastewater that has been coagulated and passed through natural undisturbed soils or a bed of filter media - maximum average of 2 NTU within a 24-hour period - not to exceed 5 NTU more than 5 percent of the time within a 24-hour period - maximum of 10 NTU at any time • Turbidity requirements for wastewater passed through membrane - not to exceed 0.2 NTU more than 5 percent of the time within a 24-hour period - maximum of 0.5 NTU at any time							

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
Colorado	*Landscape irrigation excluding single-family residential:* • Oxidized, filtered and disinfected • E. coli - 126/100 ml (monthly average) - 235/100 ml (single sample maximum in any calendar month) • Turbidity - not to exceed 3 NTU (monthly average) - not to exceed 5 NTU in more than 5 percent of the individual analytical results (any calendar month) *Single-family residential:* • Oxidized, coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median)	*Treaters:* • Quality of reclaimed domestic wastewater produced and delivered at the point of compliance *Applicators:* • Total volume of reclaimed domestic wastewater applied per year or season • The maximum monthly volume applied • Each location with the associated acreage where reclaimed domestic wastewater was applied			• Application rates shall protect surface and groundwater quality and irrigation shall be controlled to minimize ponding		*Landscape irrigation excluding single-family residential:* • No impoundment or irrigation of reclaimed water within 100 feet of any well used for domestic supply unless, in the case of impoundment, it is lined with a synthetic material with a permeability of 10^{-6} cm/sec or less *Single-family residential:* • No irrigation of reclaimed water within 500 feet of any domestic supply well • No irrigation of reclaimed water within 100 feet of any irrigation well	

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates [1]	Groundwater Monitoring [1]	Setback Distances [1] [2]	Other
	- 23/100 ml (any sample)							
Delaware	• Advanced treatment using oxidation, clarification, coagulation, flocculation, filtration, and disinfection • 10 mg/l BOD$_5$ • 10 mg/l TSS • Turbidity not to exceed 5 NTU • Fecal coliform - 20/100 ml	• Continuous on-line monitoring for turbidity before application of the disinfectant • Continuous on-line monitoring of residual disinfection concentrations • Parameters which may require monitoring include volume of water applied to spray fields, BOD, suspended solids, fecal coliform bacteria, pH, COD, TOC, ammonia nitrogen, nitrate nitrogen, total Kjeldahl nitrogen, total phosphorus, chloride, Na, K, Ca, Mg, metals, and priority pollutants • Parameters		• Storage provisions required either as a separate facility or incorporated into the pretreatment system • Minimum 15 days storage required unless other measures for controlling flow are demonstrated • Must determine operational, wet weather, and water balance storage requirements • Separate off-line system for storage of reject wastewater with a minimum capacity equal to 2 days average daily design flow required	• Maximum design wastewater loadings limited to 2.5 in/wk • Maximum instantaneous wastewater application rates limited to 0.25 in/hour • Design wastewater loading must be determined as a function of precipitation, evapotranspiration, design percolation rate, nitrogen loading and other constituent loading limitations, groundwater and drainage conditions, and average and peak design wastewater flows and seasonal fluctuations	• Required • One well upgradient of site or otherwise outside the influence of the site for background monitoring • One well within wetted field area of each drainage basin intersected by site • Two wells downgradient in each drainage basin intersected by site • One well upgradient and One well downgradient of the pond treatment and storage facilities in each drainage basin intersected by site • May require measurement of depth to groundwater,	• Determined on a case-by-case basis	• Regulations pertain to sites unlimited to public access

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
		and sampling frequency determined on case-by-case basis				pH, COD, TOC, nitrate nitrogen, total phosphorus, electrical conductivity, chloride, fecal coliform bacteria, metals, and priority pollutants • Parameters and sampling frequency determined on a case-by-case basis		
Florida	• Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 20 mg/l CBOD$_5$ (annual average) • 5 mg/l TSS (single sample) to be achieved prior to disinfection • Total chlorine residual of at least 1 mg/l after a minimum	• Parameters to be monitored and sampling frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH, chlorine residual, dissolved oxygen, suspended solids, CBOD$_5$, nutrients, and	• Class I reliability - requires multiple or back-up treatment units and a secondary power source • Minimum reject storage capacity equal to 1-day flow at the average daily design flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is	• At a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20	• Site specific • Design hydraulic loading rate - maximum annual average of 2 in/wk is recommended • Based on nutrient and water balance assessments	• Required • One upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • One well at the edge of the zone of discharge down-gradient of the site (compliance well) • One well downgradient	• 75 feet to potable water supply wells • 75 feet from reclaimed water transmission facility to public water supply well • Low trajectory nozzles required within 100 feet of outdoor public eating, drinking, and bathing facilities • 100 feet from indoor aesthetic	• Includes use of reclaimed water for irrigation of residential lawns, golf courses, cemeteries, parks, playgrounds, schoolyards, highway medians, and other public access areas • Also includes use of reclaimed water for toilet flushing, fire protection, construction

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates [1]	Groundwater Monitoring [1]	Setback Distances [1] [2]	Other
	acceptable contact time of 15 minutes at peak hourly flow • Fecal coliform - over 30 day period, 75 percent of samples below detection limits - 25/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection	fecal coliform • Continuous on-line monitoring of turbidity prior to disinfection • Continuous on-line monitoring of total chlorine residual or residual concentrations of other disinfectants • Monitoring for *Giardia* and *Cryptosporidium* based on treatment plant capacity - ≥ 1 mgd, sampling one time during each 2-year period - < 1 mgd, sampling one time during each 5-year period - samples to be taken immediately following disinfection process • Primary and secondary drinking water standards to	less • Minimum system size of 0.1 mgd (not required for toilet flushing and fire protection uses) • Staffing - 24 hrs/day, 7 days/wk or 6 hrs/day, 7 days/wk with diversion of reclaimed water to reuse system only during periods of operator presence	years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation • Existing or proposed lakes or ponds (such as golf course ponds) are appropriate for storage if it will not impair the ability of the lakes or ponds to function as a stormwater management system • Aquifer storage and recovery allowed as provision of storage		from the site and within the zone of discharge (intermediate well) • One well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for additional parameters based on site-specific conditions and groundwater quality	features using reclaimed water to adjacent indoor public eating and drinking facilities • 200 feet from unlined storage ponds to potable water supply wells	dust control, vehicle washing and aesthetic purposes • Tank trucks can be used to apply reclaimed water if requirements are met • Cross-connection control and inspection program required

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
		be monitored by facilities ≥ 100,000 gpd				quality		
Georgia	• Secondary treatment followed by coagulation, filtration, and disinfection • 5 mg/l BOD • 5 mg/l TSS • Fecal coliform - 23/100 ml (monthly average) - 100/100 ml (maximum any sample) • pH 6 - 9 • Turbidity not to exceed 3 NTU prior to disinfection • Detectable disinfectant residual at the delivery point	• Continuous turbidity monitoring prior to disinfection • Weekly sampling for TSS and BOD • Daily monitoring for fecal coliform • Daily monitoring for pH • Detectable disinfection residual monitoring	• Multiple process units • Ability to isolate and bypass all process units • System must be capable of treating peak flows with the largest unit out of service • Equalization may be required • Back-up power supply • Alarms to warn of loss of power supply, failure of pumping systems, failure of disinfection systems, or turbidity greater than 3 NTU	• Reject water storage equal to at least 3 days of flow at the average daily design flow • One of the following options must be in place to account for wet weather periods - sufficient storage onsite or at the customer's location to handle the flows until irrigation can be resumed - additional land set aside that can be irrigated without causing harm to the cover crop - obtain NPDES permit for all or part of the flow			• Determined on a case-by-case basis	
Hawaii	*R-1 water:*	• Daily flow	• Multiple or	• 20 days	• Design	• Required	*R-1 water:*	• R-1 water can

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates [(1)]	Groundwater Monitoring [(1)]	Setback Distances [(1) (2)]	Other
	• Oxidized, filtered, and disinfected • Fecal coliform – 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 200/100 ml (maximum any one sample) • Inactivation and/or removal of 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus • Effluent turbidity not to exceed 2 NTU • Chemical pretreatment facilities required in all cases where granular media filtration is used; not required for facilities using membrane filtration	monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and recording of chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of BOD_5 and suspended solids	standby units required with sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved	application rate determined by water balance	• Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on site size, site characteristics, location, method of discharge, and other appropriate considerations • One well upgradient and two wells downgradient for project sites 500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than	• Minimum of 50 feet to drinking water supply well • Outer edge of impoundment at least 100 feet from any drinking water supply well *R-2 water:* • For spray irrigation applications, 500 feet to residence property or a place where public exposure could be similar to that at a park, elementary school yard or athletic field • Minimum of 100 feet to any drinking water supply well • Outer edge of impoundment at least 300 feet from any drinking water supply well	be used for spray Irrigation of golf courses, parks, elementary schoolyards, athletic fields, landscapes around some residential property, roadside and median landscapes, landscape impoundments with decorative fountain, and decorative fountains • R-1 water can also be used for flushing toilets and urinals, fire fighting and washing yards, lots and sidewalks • R-2 water can be used as source of supply for landscape impoundments without decorative fountain and construction uses

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	• Theoretical chlorine contact time of 120 minutes and actual modal contact time of 90 minutes throughout which the chlorine residual is 5 mg/l *R-2 water:* • Oxidized and disinfected • Fecal coliform – 23/100 ml (7-day median) - 200/100 ml (not to exceed in more than one sample in any 30-day period) • Theoretical chlorine contact time of 15 minutes and actual modal contact time of 10 minutes throughout which the chlorine residual is 0.5 mg/l					200 acres • Additional lysimeters may be necessary to address concerns of public health or environmental protection as related to variable characteristics of the subsurface or of the operations of the project		• If alternative application methods are used, such as subsurface, drip or surface irrigation, a lesser quality reclaimed water may be suitable • R-2 water used in spray irrigation will be performed during periods when the area is closed to the public and the public is absent from the area, and end at least 1 hour before the area is open to the public • Subsurface irrigation may be performed at any time
Idaho	• Oxidized,							• Includes

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State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median)							irrigation of parks, playgrounds, schoolyards and other areas where children are more likely to have access or exposure • Irrigation to be accomplished during periods of non-use
Illinois	• Two-cell lagoon system with tertiary sand filtration and disinfection or mechanical secondary treatment with disinfection			• Minimum storage capacity equal to at least 150 days of wastewater at design average flow except in southern Illinois areas where a minimum of 120 days of storage capacity to be provided • Storage can be determined based on a rational design that must include capacity for the wettest year with a 20-year	• Based on the limiting characteristic of the treated wastewater and the site • Balances must be calculated and submitted for water, nitrogen, phosphorus, and BOD	• Required • One well upgradient for determining background concentrations • Two wells downgradient in the dominant direction of groundwater movement • Wells between each potable water well and the application area if within 1,000 feet • Monitoring of nitrates, ammonia nitrogen, chlorides, sulfates, pH, total dissolved	• 200 feet to residential lot lines	

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
				return frequency		solids, phosphate, and coliform bacteria		
Indiana	• Secondary treatment and disinfection • 10 mg/l BOD_5 • 5 mg/l TSS prior to disinfection (24 hour average) • Fecal coliform - no detectable fecal coliform (7-day median) – 14/100 ml (single sample) • pH 6 - 9 • Total chlorine residual after a minimum contact time of 30 minutes at least 1 mg/l (if chlorination is used for disinfection)	• Daily monitoring of TSS, coliform, and chlorine residual • Weekly monitoring of BOD and pH • Monthly monitoring of total nitrogen, ammonium nitrogen, nitrate nitrogen, phosphorus, and potassium • Annual monitoring of arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc	• Alternate power source required	• Minimum of 90 days effective storage capacity required	• Maximum hydraulic loading rate of 2 in/week		• 200 feet to potable water supply wells or drinking water springs • 300 feet to any waters of the state • 300 feet to any residence	• Pertains to land with a high potential for public exposure
Kansas	• Secondary treatment with filtration and disinfection for irrigation of areas with a high probability of body contact			• Storage provided to retain a minimum of 90 days average dry weather flow when no discharge to surface water is available	• Maximum daily application rate of 3 in/ac/day • Maximum annual application rate of 40 in/acre • Based on soil and crop moisture	• Site specific • May be required	• None required	• Projected uses include irrigation of golf courses or public parks with a low probability of body contact • Public access prohibited

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
					and/or nutrient requirements of selected crop			during and 8 hours after irrigation
Massachusetts	*Toilet flushing:* • Secondary treatment with filtration (possibly) and disinfection • pH 6 - 9 • 30 mg/l BOD_5 • Turbidity - 5 NTU (not to exceed at any time) • Fecal coliform - 100/100 ml (single sample) • 10 mg/l TSS • 10 mg/l total nitrogen • Class I groundwater permit standards (SDWA Drinking Water Standards)	*Toilet flushing:* • pH - weekly or daily • BOD - weekly • Turbidity - continuous monitoring prior to disinfection • Fecal coliform -once per week • Disinfection UV intensity - daily or chlorine residual - daily • TSS - weekly • Nitrogen - twice per month • Permit standards - variable testing requirements	• EPA Class I Reliability standards may be required • Two independent and separate sources of power • Unit redundancy • Additional storage	• Immediate, permitted discharge alternatives are required for emergency situations and for non-growing season disposal				• The use of reclaimed water for toilet flushing is allowed at commercial facilities where public access to the plumbing is not allowed
Montana	• Oxidized, clarified, coagulated, filtered, and disinfected • Fecal coliform - 2.2/100 ml (7-day median) - 23/100 ml (single sample) • Turbidity	• Effluent to be monitored on a regular basis to show the biochemical and bacteriological quality of the applied wastewater • Monitoring			• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013 • Hydraulic loading must be based on	• Determined on a case-by-case basis • Consideration is given to groundwater characteristics, past practices, depth to groundwater, cropping	• 100 feet to any water supply well • Distance to surface water determined on a case-by-case basis based on quality of effluent and the level of	• Includes landscape irrigation of parks, playgrounds, schoolyards, unrestricted golf courses, and other areas where the public has

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	- 2 NTU (average) - 5 NTU (not to exceed more than 5 percent of the time during any 24-hour period)	frequency to be determined on a case-by-case basis			the wettest year in ten years	practices, etc.	disinfection	similar access or exposure
Nevada	• At a minimum, secondary treatment with disinfection • 30 mg/l BOD_5 • Fecal coliform - 2.2/100 ml (30-day geometric mean) - 23/100 ml (maximum daily number)						• None required	• Uses include irrigation of cemeteries, golf courses, greenbelts, parks, playgrounds, or commercial or residential lawns
New Jersey	• Fecal Coliform - 2.2/100 ml (7-day median) - 14/100 ml (maximum any one sample) • Minimum chlorine residual - 1.0 mg/l after 15-minute contact at peak hourly flow • Alternative methods of disinfection, such as UV and ozone, may be	• Continuous on-line monitoring of chlorine residual produced oxidant at the compliance monitoring point • For spray irrigation, chlorination levels for disinfection should be continually evaluated to ensure		• Not required when another permitted reuse system or effluent disposal system is incorporated into the system design • If system storage ponds are used, they do not have to be lined • Reject storage ponds shall be lined or sealed to prevent	• Hydraulic loading rate - maximum annual average of 2 in/wk but may be increased based on a site-specific evaluation • The spray irrigation of reclaimed water shall not produce surface runoff or ponding		• 75 feet to potable water supply wells that are existing or have been approved for construction • 75 feet provided from a reclaimed water transmission facility to all potable water supply wells • 100 feet from outdoor public eating,	• Secondary treatment, for the purpose of the manual, refers to the existing treatment requirements in the NJPDES permit, not including the additional reclaimed water for beneficial reuse treatment requirements • A chlorine

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	approved • TSS not to exceed 5 mg/l before disinfection • Total nitrogen - 10 mg/l but may be less stringent if higher limit is still protective of environment • Secondary • Filtration • Chemical addition prior to filtration may be necessary	chlorine residual levels do not adversely impact vegetation • Continuous monitoring for turbidity before disinfection is required • Operating protocol required • User/Supplier Agreement • Annual usage report		measurable seepage • Existing or proposed ponds (such as golf course ponds) are appropriate for storage of reuse water if the ability of the ponds to function as stormwater management systems is not impaired			drinking, and bathing facilities • 100 feet between indoor aesthetic features and adjacent indoor public eating and drinking facilities when in the same room or building	residual of 0.5 mg/l or greater is recommended to reduce odors, slime, and bacterial re-growth
New Mexico	• Adequately treated and disinfected • Fecal coliform - 100/100 ml	• Fecal coliform sample taken at point of diversion to irrigation						• Includes irrigation of parks, playgrounds, schoolyards, golf courses, cemeteries, and other areas where the public has similar access or exposure
North Carolina	• Tertiary quality effluent (filtered or equivalent) • TSS - 5 mg/l (monthly average) - 10 mg/l (daily maximum)	• Continuous on-line monitoring and recording for turbidity or particle count and flow prior to discharge	• All essential treatment units to be provided in duplicate • Five-day side-stream detention pond required for effluent exceeding	• Determined using a mass water balance based upon a recent 25-year period using monthly average precipitation data, potential	• Site specific • Application rate may take both the maximum soil absorption and water needs of the receiving crop into consideration		• 100 feet to any surface waters classified SA, including wetlands • 25 feet to any surface water not classified SA, including wetlands and	• Uses include irrigation of residential lawns, golf courses, parks, school grounds, industrial or commercial site grounds,

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	• Fecal coliform - 14/100 ml (monthly geometric mean) - 25/100 ml (daily maximum) • BOD_5 - 10 mg/l (monthly average) - 15 mg/l (daily maximum) • NH_3 - 4 mg/l (monthly average) - 6 mg/l (daily maximum) • Turbidity not to exceed 10 NTU at any time		turbidity or fecal coliform limits • Automatically activated standby power source to be provided • Certified 24 hours/day operator with a grade level equivalent to or greater than the facility classification	evapotranspiration data, and soil drainage data • No storage facilities required if it can be demonstrated that other permitted disposal options are available			any swimming pool • 100 feet to any water supply well • 10 feet to any nonpotable well	landscape areas, highway medians, and roadways • Can also be used for aesthetic purposes such as decorative ponds or fountains, dust control, soil compaction, street cleaning, vehicle washing, urinal and toilet flushing, or fire protection in sprinkler systems located in commercial or industrial facilities
North Dakota	• At a minimum, secondary treatment with chlorination • 25 mg/l BOD_5 • 30 mg/l TSS • Fecal coliform - 200/100 ml • Chlorine residual of at least 0.1 mg/l	• BOD_5, TSS, and fecal coliform monitoring once every 2 weeks • Daily monitoring of chlorine residual at the point of use farthest from the treatment plant						• Use applies to irrigation of public property such as parks and golf courses • Signs must be posted in visible areas during irrigation and for 2 hours after irrigation is completed
Ohio	• Biological	*Large system*		• Operational	• Determined by	• Monitoring	• 100 feet to	• Includes parks,

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	treatment and disinfection • 25 mg/l $CBOD_5$ • Fecal coliform (30-day average) - 23/100 ml with no public access buffer area or night application • Limits for metals	*monitoring (150,000 to 500,000 gpd):* • Twice weekly for $CBOD_5$, total coliform (when irrigating) and storage volume • Monthly monitoring for total inorganic nitrogen • Daily monitoring for flow *Small system monitoring (<150,000 gpd):* • Weekly monitoring of $CBOD_5$, total coliform (when irrigating) and storage volume • Daily monitoring of flow		storage of 4 times the daily design flow needed • Storage provisions for at least 130 days of design average flow needed for periods when irrigation is not recommended • Actual storage requirements determined by performing water balance • Permits can be obtained for stream discharge during winter and times of high stream flow to reduce storage needs	calculating a water and nutrient balance	wells upgradient and downgradient of large irrigation systems • Monitoring wells should be sampled at the beginning and the end of the irrigation season	private water well • 300 feet to community water well • 100 feet to sink hole • 50 feet to drainage way • 50 feet to surface water • 100 feet to road right-of-way without windbreak using spray irrigation • 10 feet to road right-of-way with windbreak or with flood irrigation • 50 feet to property line	golf courses, lawns, highway medians, and playing fields
Oregon	*Parks, playgrounds, schoolyards, and golf courses with contiguous residences:* • Level IV - biological treatment, clarification,	*Parks, playgrounds, schoolyards, and golf courses with contiguous residences:* • Total coliform sampling - one time a day	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment facilities and monitoring				*Parks, playgrounds, schoolyards, and golf courses with contiguous residences:* • None required *Landscape impoundments and construction*	• No direct public contact is allowed during the irrigation cycle

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	coagulation, filtration, and disinfection • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (maximum any sample) • Turbidity - 2 NTU (24-hour mean) - 5 NTU (5 percent of time during a 24-hour period) *Landscape impoundments and construction use:* • Level II - biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) - 23/100 ml (7-day median)	• Turbidity - hourly *Landscape impoundments and construction use:* • Total coliform sampling - once a week	equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment				*use:* • 10-foot buffer with surface irrigation • 70-foot buffer with spray irrigation • No spray irrigation within 100 feet of drinking fountains or food preparation areas	
South Carolina	• Advanced wastewater treatment • BOD$_5$ and TSS - 5 mg/l (monthly average) - 7.5 mg/l	• Minimum of one fecal or total coliform presence/ absence measurement daily • Nitrate		• Storage facilities are not required to be lined • Covered storage systems or other	• Hydraulic - maximum of 0.5 - 2 in/wk depending on depth to groundwater • A nitrate to nitrogen	• May be required	• None required	• Applies to application of reclaimed water in areas with a high potential for contact • Includes

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	(weekly average) • Turbidity - 1 NTU (monthly average) - 5 NTU (not to exceed based on an average for 2 consecutive days) • Total coliform - similar to standards in State Primary Regulations - for a system that collects at least 40 samples per month, if no more than 5 percent are total coliform-positive, the system will be in compliance with the MCL for total coliform • Total chlorine residual limits based on site conditions and distribution system design	monitoring required		alternative methods may be required to maintain effluent quality prior to distribution	loading balance may be required • Application rates in excess of 2 in/wk may be approved			residential irrigation systems, multifamily irrigation systems, commercial irrigation systems in common residential areas, public parks, and open spaces
South Dakota	• Secondary treatment and disinfection			• Minimum of 210 days capacity	• Maximum application rate limited to	• Shallow wells in all directions of major		

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates $^{(1)}$	Groundwater Monitoring $^{(1)}$	Setback Distances $^{(1)\,(2)}$	Other
	• Total coliform - 200/100 ml (geometric mean)			without consideration for evaporation	2 in/acre/wk or a total of 24 in/acre/yr	groundwater flow from site and no more than 200 feet outside of the site perimeter, spaced no more than 500 feet apart, and extending into the groundwater table • Shallow wells within the site are also recommended		
Tennessee	• Biological treatment • Additional treatment requirements are determined on a case-by-case basis • Disinfection required • 30 mg/l BOD$_5$ and TSS (monthly average) • Fecal coliform - 200/100 ml	• Site specific		• Storage requirements determined by either of two methods 1) use of water balance calculations or, 2) use of a computer program that was developed based upon an extensive NOAA study of climatic variations throughout the United States	• Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - based on water balance using 5-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 feet to site boundary • 50 feet to on site streams, ponds, and roads *Spray Irrigation:* [1] Open Fields • 300 feet to site boundary • 150 feet to on site streams, ponds, and roads [2] Forested • 150 feet to site boundary • 75 feet to on site streams, ponds, and roads	• Pertains to irrigation of parks, green areas, and other public or private land where public use occurs or is expected to occur
Texas	• Type I	• Sampling and			• Based on			• Type I

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	reclaimed water *Reclaimed water on a 30-day average to have a quality of:* • 5 mg/l BOD_5 or $CBOD_5$ • 10 mg/l for landscape impoundment) • Turbidity - 3 NTU • Fecal coliform - 20/100 ml (geometric mean) - 75/100 ml (not to exceed in any sample)	analysis twice per week for BOD_5 or $CBOD_5$, turbidity, and fecal coliform • Periodic fecal coliform sampling in the reclaimed water distribution system may be necessary			water balance			reclaimed water use defined as use of reclaimed water where contact between humans and the reclaimed water is likely • Uses include residential irrigation, irrigation of public parks, golf courses with unrestricted public access, schoolyards or athletic fields, fire protection, toilet flushing, and other uses
Utah	• Type I treated wastewater - secondary treatment with filtration and disinfection • 10 mg/l BOD (monthly average) • Turbidity prior to disinfection - not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any	• Daily composite sampling required for BOD • Continuous turbidity monitoring prior to disinfection • Daily monitoring of fecal coliform • Continuous total residual chlorine	• Alternative disposal option or diversion to storage required if turbidity or chlorine residual requirements not met				• 50 feet to any potable water well • Impoundments at least 500 feet from any potable water well	• Uses allowed where human exposure is likely include residential irrigation, non-residential landscape irrigation, golf course irrigation, toilet flushing, fire protection, and other uses • For residential landscape

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	time • Fecal coliform - none detected (weekly median as determined from daily grab samples) - 14/100 ml (not to exceed in any sample) • 1.0 mg/l total residual chlorine after 30 minutes contact time at peak flow • pH 6 - 9	monitoring • pH monitored continuously or by daily grab samples						irrigation at individual homes, additional quality control restrictions may be required
Washington	*Landscape irrigation, decorative fountains, street cleaning, fire protection, and toilet flushing:* • Class A - oxidized, coagulated, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) *Landscape impoundment and construction uses:*	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples collected at least daily • Continuous on-line monitoring of turbidity	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity	• Hydraulic loading rate to be determined based on a detailed water balance analysis	• May be required • Monitoring program will be based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics, and other considerations	• 50 feet to any potable water supply well • Unlined impoundments - 500 feet between perimeter and any potable water supply well • Lined impoundments - 100 feet between perimeter and any potable water supply well	• Uses include irrigation of open access areas (such as golf courses, parks, playgrounds, schoolyards, residential landscapes, or other areas where the public has similar access or exposure to the reclaimed water) and use in decorative fountains and landscape impoundments

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
	• Class C - oxidized and disinfected • Total coliform - 23/100 ml (7-day mean) - 240/100 ml (single sample) *General compliance requirements:* • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes		call at all times the irrigation system is operating	should be the volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted				• Also includes use for street cleaning, construction, fire protection in hydrants or sprinkler systems, toilet flushing in commercial or industrial facilities and in apartments and condos where the residents do not have access to the plumbing system
Wyoming	• Minimum of Class A wastewater - advanced treatment and/or secondary treatment and disinfection • Fecal coliform - 2.2/100 ml or less	• Treated wastewater to be analyzed for fecal coliform, nitrate as N, ammonia as N, and pH at a minimum • Monitoring frequency - once per month for	• Multiple units and equipment • Alternative power sources • Alarm systems and instrumentation • Operator certification and standby capability • Bypass and	• Emergency storage	• Will be applied for the purpose of beneficial reuse and will not exceed the irrigation demand of the vegetation at the site • Not to be applied at a rate greater than the		• 30 feet to adjacent property lines • 30 feet to all surface waters • 100-feet to all potable water supply wells • 100-foot buffer zone around spray site	• Pertains to land with a high potential for public exposure

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Table A-1. Unrestricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates (1)	Groundwater Monitoring (1)	Setback Distances (1) (2)	Other
		lagoon systems - once per week for mechanical systems • Frequency specified in NPDES permit required if more frequent	dewatering capability • Emergency storage		agronomic rate for the vegetation at the site • Will be applied in a manner and time that will not cause any surface runoff or contamination of a groundwater aquifer			

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
Alabama	• Minimum EPA secondary, or equivalent to secondary, limits and appropriate disinfection • If wastewater stabilization pond is used, pond must meet ADEM requirements with second cell being used as a holding pond • Mechanical systems, if used, should allow as little nitrification as possible • Disinfection must be performed through one of the following processes - breakpoint chlorination, ozonation, or ultraviolet disinfection - storage of the treated wastewater for a period of 20 days in a holding pond prior to		• Controls required to indicate any system malfunction or permit varied field operations	• Based on water balance performed on a monthly basis with a precipitation input using a 5-year, 24-hour rainfall event, 30-year minimum base period • In addition to storage dictated by water balance, a minimum of 15 days storage should be provided for contingencies	• Based on soil permeability and nitrogen limits (10 mg/l nitrate) • Excessive rainwater run-off should be diverted • Excessive ponding should be avoided	• At least three downgradient monitoring wells • At least one upgradient monitoring well • Contaminants in groundwater not to exceed primary and secondary maximum contaminant levels • Minimum depth to groundwater, without use of an underdrain collection system, shall be 4 feet	• 100 feet to property lines • 300 feet to existing habitable residences • Spray irrigation not allowed within 100 feet of any perennial lake or stream • If irrigation causes an intermittent stream to become perennial, the irrigation must cease within 100 feet of the stream • Spray irrigation not allowed in wellhead protection area (WHPA 1) – if no wellhead delineation exists, minimum distance for application shall be 1,000 feet or as required • No sites within 100-year floodplain	• Disinfection required for public access areas such as golf courses • May use breakpoint chlorination with rapid, uniform mixing to a free chlorine residual of 2 mg/l at a contact period of 30 minutes at average daily flow rate • May use ozonation or ultraviolet disinfection systems; a geometric mean limit of 126/100 ml for E. Coli, or 33/ 100 ml for enterococci bacteria will be required; the total suspended solids concentration of the effluent, prior to disinfection, must be no more than 5 mg/l which

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	discharge to the application site							may require installation of a filtration process
Arizona	• Class B reclaimed water - secondary treatment and disinfection • Fecal coliform - 200/100 ml (not to exceed in 4 of the last 7 daily samples) - 800/100 ml (single sample maximum)	• Case-by-case basis			• Application rates based on either the water allotment assigned by the Arizona Department of Water Resources (a water balance that considers consumptive use of water by the crop, turf, or landscape vegetation) or an alternative approved method			• Includes irrigation of golf courses and other restricted access landscapes • Application methods that reasonably preclude human contact with reclaimed water will be used when irrigating
Arkansas	• Secondary treatment and disinfection	• As required by regulatory agency		• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • One well upgradient • One well within site • One well downgradient • More wells may be required on a case-by-case basis	• Determined on case-by-case basis	
California	• Disinfected secondary-23 recycled water - oxidized and disinfected • Total coliform	• Total coliform - sampled at least once daily from the disinfected effluent	• Warning alarms • Back-up power source • Multiple treatment units				• No irrigation with, or impoundment of, disinfected secondary-23 recycled water	• Includes landscape irrigation of cemeteries, freeway landscapes,

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	- 23/100 ml (7-day median) - 240/100 ml (not to exceed in more than one sample in any 30-day period)		capable of treating entire flow with one unit not in operation or storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of qualified personnel				within 100 feet of any domestic water supply well • No spray irrigation within 100 feet of a residence or a place where public exposure could be similar to that of a park, playground, or schoolyard	and restricted access golf courses
Colorado	• Secondary treatment with disinfection • E. coli - 126/100 ml (monthly average) - 235/100 ml (single sample maximum in any calendar month) • 30 mg/l TSS as a daily maximum	*Treaters:* • Quality of reclaimed domestic wastewater produced and delivered at the point of compliance *Applicators:* • Total volume of reclaimed domestic wastewater applied per year or season • The maximum monthly volume applied • Each location with the associated acreage where			• Application rates shall protect surface and groundwater quality and irrigation shall be controlled to minimize ponding		• No impoundment or irrigation of reclaimed water within 100 feet of any well used for domestic supply unless, in the case of an impoundment, it is lined with a synthetic material with a permeability of 10^{-6} cm/sec or less	

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
		reclaimed domestic wastewater was applied • The beginning and end time for each date that reclaimed domestic wastewater is applied						
Delaware	• Biological treatment and disinfection • 30 mg/l BOD_5 • 30 mg/l TSS • Fecal coliform - 200/100 ml	• Continuous on-line monitoring of residual disinfection concentrations • Parameters which may require monitoring include volume of water applied to spray fields, BOD, suspended solids, fecal coliform bacteria, pH, COD, TOC, ammonia nitrogen, nitrate nitrogen, total Kjeldahl nitrogen, total phosphorus, chloride, Na, K, Ca, Mg, metals, and priority		• Storage provisions required either as a separate facility or incorporated into the pretreatment system • Minimum 15 days storage required unless other measures for controlling flow are demonstrated • Must determine operational, wet weather, and water balance storage requirements • Separate off-line system for storage of reject wastewater with a	• Maximum design wastewater loadings limited to 2.5 in/wk • Maximum instantaneous wastewater application rates limited to 0.25 in/hour • Design wastewater loading must be determined as a function of precipitation, evapotranspiration, design percolation rate, nitrogen loading and other constituent loading limitations, groundwater and drainage conditions, and	• Required • One well upgradient of site or otherwise outside the influence of the site for background monitoring • One well within wetted field area of each drainage basin intersected by site • Two wells down-gradient in each drainage basin intersected by site • One well upgradient and One well downgradient of the pond treatment and storage facilities in	• Determined on a case-by-case basis	• Regulations pertain to sites limited to public access at specific periods of time

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
		pollutants • Parameters and sampling frequency determined on a case-by-case basis		minimum capacity equal to 2-day average daily design flow required	average and peak design wastewater flows and seasonal fluctuations	each drainage basin intersected by site • May require measurement of depth to groundwater, pH, COD, TOC, nitrate nitrogen, total phosphorus, electrical conductivity, chloride, fecal coliform bacteria, metals, and priority pollutants • Parameters and sampling frequency determined on a case-by-case basis		
Florida	• Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 20 mg/l $CBOD_5$ (annual average) • 5 mg/l TSS (single sample) • Total chlorine	• Parameters to be monitored and sampling frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH,	• Class I reliability - requires multiple or back-up treatment units and a secondary power source • Minimum reject storage capacity equal to 1 day flow at the average daily design	• At a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or disposal system is permitted • Water balance	• Site specific • Design hydraulic loading rate - maximum annual average of 2 in/wk is recommended • Based on nutrient and water balance assessments	• Required • One upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • One well at the edge of the zone of	• 75 feet to potable water supply wells • 75 feet from reclaimed water transmission facility to public water supply well • Low trajectory nozzles required within 100 feet of outdoor public	• Rules do not differentiate between unrestricted and restricted urban reuse • Tank trucks can be used to apply reclaimed water if requirements are met • Cross-connection

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	residual of at least 1 mg/l after a minimum acceptable contact time of 15 minutes at peak hourly flow • Fecal coliform - over 30-day period, 75 percent of samples below detection limits - 25/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection	chlorine residual, dissolved oxygen, suspended solids, $CBOD_5$, nutrients, and fecal coliform • Continuous on-line monitoring of turbidity prior to disinfection • Continuous on-line monitoring of total chlorine residual or residual concentrations of other disinfectants • Monitoring for *Giardia* and *Cryptosporidium* based on treatment plant capacity - ≥ 1 mgd, sampling one time during each two-year period - < 1 mgd , sampling one time during each 5-year period - samples to be taken immediately	flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • Minimum system size of 0.1 mgd (not required for toilet flushing and fire protection uses) • Staffing - 24 hrs/day, 7 days/wk or 6 hrs/day, 7 days/wk with diversion of reclaimed water to reuse system only during periods of operator presence	required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation • Existing or proposed lakes or ponds (such as golf course ponds) are appropriate for storage if it will not impair the ability of the lakes or ponds to function as a stormwater management system • Aquifer storage and recovery allowed as provision of storage		discharge downgradient of the site (compliance well) • One well downgradient from the site and within the zone of discharge (intermediate well) • One well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for	eating, drinking, and bathing facilities • 100 feet from indoor aesthetic features using reclaimed water to adjacent indoor public eating and drinking facilities • 200 feet from unlined storage ponds to potable water supply wells	control and inspection program required

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
		following disinfection process - Primary and secondary drinking water standards to be monitored by facilities ≥ 100,000 gpd				additional parameters based on site-specific conditions and groundwater quality		
Georgia	- Secondary treatment followed by coagulation, filtration, and disinfection - 5 mg/l BOD - 5 mg/l TSS - Fecal coliform - 23/100 ml (monthly average) - 100/100 ml (maximum any sample) - pH 6 - 9 - Turbidity not to exceed 3 NTU prior to disinfection - Detectable disinfectant residual at the delivery point	- Continuous turbidity monitoring prior to disinfection - Weekly sampling for TSS and BOD - Daily monitoring for fecal coliform - Daily monitoring for pH - Detectable disinfection residual monitoring	- Multiple process units - Ability to isolate and bypass all process units - System must be capable of treating peak flows with the largest unit out of service - Equalization may be required - Back-up power supply - Alarms to warn of loss of power supply, failure of pumping systems, failure of disinfection systems, or turbidity greater than 3 NTU	- Reject water storage equal to at least 3 days of flow at the average daily design flow - One of the following options must be in place to account for wet weather periods - sufficient storage onsite or at the customer's location to handle the flows until irrigation can be resumed - additional land set aside that can be irrigated without causing harm to the cover crop			- Determined on a case-by-case basis	

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
				- An NPDES permit for all or part of the flow				
Hawaii	• R-2 water - oxidized and disinfected • Fecal coliform - 23/100 ml (7-day median) - 200/100 ml (not to exceed in more than one sample in any 30-day period) • Theoretical chlorine contact time of 15 minutes and actual modal contact time of 10 minutes throughout which the chlorine residual is 0.5 mg/l	• Daily flow monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and recording of chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of BOD_5 and suspended solids	• Multiple or standby units required with sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved	• Design application rate determined by water balance	• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on site size, site characteristics, location, method of discharge. and other appropriate considerations • One well upgradient and two wells downgradient for project sites 500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites	*R-2 water:* • For spray irrigation applications, 500 feet to residence property or a place where public exposure could be similar to that at a park, elementary schoolyard, or athletic field • Minimum of 100 feet to any drinking water supply well • Outer edge of impoundment at least 300 feet from any drinking water supply well	• R-2 water can be used for spray irrigation of freeway and cemetery landscapes and other areas where access is controlled • If alternative application methods are used, such as subsurface, drip or surface irrigation, a lesser quality reclaimed water may be suitable • R-2 water used in spray irrigation will be performed when the area is closed to the public and the public is absent from the area, and will end at least 1 hour before the area is open to the public • Subsurface irrigation may

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
						that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address public health or environmental protection concerns related to variable characteristics of the subsurface or of the operations of the project		be performed at any time
Idaho	• Oxidized and disinfected • Total coliform - 23/100 ml (7 day median)							• Includes irrigation of golf courses, cemeteries, roadside vegetation, and other areas where individuals have access or exposure • Irrigation to be accomplished during periods of non-use
Illinois	• Two-cell lagoon system with tertiary sand filtration and disinfection or			• Minimum storage capacity equal to at least 150 days of wastewater at	• Based on the limiting characteristic of the treated wastewater and the site	• Required • One well upgradient for determining background concentrations	• 25 feet to any residential lot line if surrounded by a fence with a minimum	

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	mechanical secondary treatment with disinfection			design average flow except in southern Illinois areas where a minimum of 120 days of storage capacity to be provided • Storage can be determined based on a rational design that must include capacity for the wettest year with a 20-year return frequency	• Balances must be calculated and submitted for water, nitrogen, phosphorus, and BOD	• Two wells downgradient in the dominant direction of groundwater movement • Wells between each potable water well and the application area if within 1,000 feet • Monitoring of nitrates, ammonia nitrogen, chlorides, sulfates, pH, total dissolved solids, phosphate, and coliform bacteria	height of 40 inches • No buffer required if irrigation of golf course occurs only during the hours between dusk and dawn • No buffer required if the application and its associated drying time occur during a period when the area is closed to the public	
Indiana	• Secondary treatment and disinfection • 30 mg/l BOD_5 • 30 mg/l TSS • Fecal coliform - 200/100 ml (7-day median) - 800/100 ml (single sample) • pH 6 - 9 • Total chlorine residual after a minimum contact time of 30 minutes at least 1 mg/l (if	• Daily monitoring of TSS, coliform, and chlorine residual • Weekly monitoring of BOD and pH • Monthly monitoring of total nitrogen, ammonium nitrogen, nitrate nitrogen, phosphorus, and potassium	• Alternate power source required	• Minimum of 9 days effective storage capacity required	• Maximum hydraulic loading rate of 2 in/week		• 200 feet to potable water supply wells or drinking water springs • 300 feet to any waters of the state • 300 feet to any residence	• Public access to be restricted for 30 days after land application of wastewater

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	chlorination is used for disinfection)	• Annual monitoring of arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc						
Iowa	• At a minimum, treatment equivalent to that obtained from a primary lagoon cell • Disinfection - required for all land application systems with spray irrigation application technique - must precede actual spraying of the wastewater on to a field area and must not precede storage - minimum contact time of 15 minutes with equipment necessary to maintain a residual chlorine level of 0.5 mg/l	• Monitoring of the following parameters required unless it has been demonstrated that they are present in insignificant amounts in the influent wastewater: total organic carbon, total dissolved solids, sodium absorption ratio, electrical conductivity, total nitrogen, ammonia nitrogen, organic nitrogen, nitrate nitrogen, total phosphorus, chloride, pH, alkalinity, hardness, trace	• Minimum of two storage cells required capable of series and parallel operation	• Minimum days of storage based on climatic restraints • When flows are generated only during the application period, a storage capacity of 45 days or the flow generated during the period of operation (whichever is less) must be provided • When discharging to a receiving waterway on a periodic basis, storage for 180 days of average wet weather flow is required	• Determined by using a water balance per month of operation	• Monitoring required adjacent to the site both upstream and downstream of the site in reference to the general groundwater flow direction	• 300 feet to existing dwellings or public use areas (not including roads and highways) • 400 feet to any existing potable water supply well not located on property • 300 feet to any structure, continuous flowing stream, or other physiographic feature that may provide direct connection between the groundwater table and the surface • Wetted disposal area to be at least 50 feet inside the property	• Categorized as land application using slow rate system (irrigation) • Application to public use areas given as example of permissible application with requirements - public not allowed into an area when spraying is being conducted - any drinking water fountains located on or near the application area must be protected - for golf courses using "wastewater", notice of its use must be

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
		elements, and coliform bacteria • Location of monitoring in effluent prior to site application • Reporting frequency depends on size of system					line of the land application site • 1,000 feet to any shallow public water supply well • 500 feet to any public lake or impoundment • _ mile to any public lake or impoundment used as a source of raw water by a potable water supply	given and warning signs posted
Kansas	• Secondary treatment and disinfection for irrigation of areas with a low probability of body contact			• Storage provided to retain a minimum of 90-days average dry weather flow when no discharge to surface water is available	• Maximum daily application rate of 3 in/ac/day • Maximum annual application rate of 40 in/acre • Based on soil and crop moisture and/or nutrient requirements of selected crop	• Site specific • May be required	• None required	• Projected uses include irrigation of golf courses or public parks with a low probability of body contact
Maryland	• 70 mg/l BOD • 90 mg/l TSS • Fecal coliform - 3/100 ml • pH 6.5 - 8.5			• Minimum of 60-days storage to be provided for all systems receiving wastewater flows throughout the	• Maximum application rate of 2 in/wk on annual average basis • Water balance required based on wettest year in the last 10	• May be required • One well upgradient of site • Two wells adjacent to the property line and	• 200 feet to property lines, waterways, and roads for spray irrigation • 500 feet to housing developments and parks for	• Pertains to golf course irrigation

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
				year	years of record • Actual application rate accepted must consider permeability of the soils, depth to groundwater, and the nutrient balance of the site	downgradient of site • Monitoring frequency determined on a case-by-case basis	spray irrigation • Reduction of the buffer zone up to 50 percent will be considered with adequate windbreak • Minimum buffer zone of 50 feet for all other types of slow rate systems	
Massachusetts	• Secondary treatment with filtration and disinfection • pH 6 - 9 • 10 mg/l BOD_5 • Turbidity - 2 NTU (average over 24-hour period) - 5 NTU (not to exceed at any time) • Fecal coliform - no detectable colonies (7-day median) - 14/100 ml (single sample) • 5 mg/l TSS • 10 mg/l total nitrogen • Class I groundwater permit standards	• pH - daily • BOD - weekly • Turbidity - continuous monitoring prior to disinfection • Fecal coliform - daily • Disinfection UV intensity - daily or chlorine residual - daily • TSS - twice per week • Nitrogen - twice per month • Phosphorus - twice per month • Heterotrophic plate count - quarterly • MS-2 phage - quarterly	• EPA Class I Reliability standards may be required • Two independent and separate sources of power • Unit redundancy • Additional storage	• Immediate, permitted discharge alternatives are required for emergency situations and for non-growing season disposal		• Required • Monitoring wells to be located and constructed to strategically sample the geologic units of interest between the discharges and sensitive receptors and withdrawal points • Sensitive receptors include, but are not limited to public and private wells, surface waters, embayments, and ACECs • Monitoring and testing frequency and	• 100 feet to buildings, residential property, private wells, Class A surface water bodies, and surface water intakes • Other than for private wells, using a green barrier in the form of hedges or trees placed at the dwelling side of the buffer may reduce the setback distance to 50 feet • No spray irrigation directed into Zone I of	• Includes the irrigation of golf courses • Spray irrigation must take place during non-operational hours and cannot result in any ponding

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	(SDWA Drinking Water Standards)	• Permit standards - variable testing requirements				parameters determined based on land use, effluent quality and quantity, and the sensitivity of receptors	public water supply wells	
Missouri	• Secondary treatment equivalent to treatment obtained from primary wastewater pond cell • Disinfected prior to application (not storage) • Total residual chlorine of 0.5 mg/l after 15 minutes of contact time at peak flow • Fecal coliform - 200/100 ml			• Minimum of 45 days in south with no discharge • Minimum of 90 days in north with no discharge • Based on the design wastewater flows and net rainfall minus evaporation expected for a one in 10-year return frequency for the storage period selected	• Application rates shall in no case exceed - 0.5 in/hour - 1.0 in/day - 3.0 in/week • Maximum annual application rate not to exceed a range from 4 to 10 percent of the design sustained permeability rate for the number of days per year when soils are not frozen • Nitrogen loading not to exceed the amount of nitrogen that can be used by the vegetation to be grown	• Minimum of one well between site and public supply well	• 150 feet to existing dwellings or public use areas, excluding roads or highways • 50 feet to property lines • 300 feet to potable water supply wells not on property, sinkholes, and losing streams or other structure or physiographic feature that may provide direct connection between the groundwater table and the surface	• Public restricted from area during application
Montana	• Oxidized and disinfected • Fecal coliform - 200/100 ml	• Effluent to be monitored on a regular basis to show the			• Nitrogen and hydraulic loadings determined	• Determined on a case-by-case basis • Consideration	• Buffer zones determined on a case-by-case basis if less	• Includes landscape irrigation of golf courses,

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	(7-day median) - 400/100 ml (any two consecutive samples)	biochemical and bacteriological quality of the applied wastewater • Monitoring frequency to be determined on a case-by-case basis			based on methods in EPA Manual 625/1-81-013 • Hydraulic loading must be based on the wettest year in ten years	is given to groundwater characteristics, past practices, depth to groundwater, cropping practices, etc.	than 200 feet • If low trajectory nozzles are used, the buffer zone can be reduced to 50 feet • 100 feet to any water supply well • Distance to surface water determined on a case-by-case basis based on quality of effluent and the level of disinfection	cemeteries, freeway landscapes, and landscapes in other areas where the public has similar access or exposure • Public access must be restricted during the period of application
Nebraska	• Biological treatment • Disinfected prior to application • Fecal coliform limit to be established	• Site specific			• Hydraulic loading rate should not exceed 4 in/wk • Nitrogen loading not to exceed crop uptake	• Site specific		• Includes irrigation of golf courses and other public use areas
Nevada	• At a minimum, secondary treatment with disinfection • 30 mg/l BOD_5 *No buffer zone*: • Fecal coliform - 2.2/100 ml (30-day geometric mean) - 23/100 ml (maximum						• None or 100 foot minimum buffer required depending on level of disinfection	• Uses include irrigation of golf courses, cemeteries, or greenbelts where public access to the site being irrigated is controlled and human contact with the treated effluent

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	daily number) *100' buffer zone:* • Fecal coliform - 23/100 ml (30-day geometric mean) - 240/100 ml (maximum daily number)							does not occur or cannot reasonably be expected
New Jersey	• Fecal coliform - 2.2/100 ml (7-day median) - 14/100 ml (maximum any one sample) • Minimum chlorine residual - 1.0 mg/l after 15-minute contact at peak hourly flow • Alternative methods of disinfection, such as UV and ozone, may be approved • TSS not to exceed 5 mg/l before disinfection • Total nitrogen - 10 mg/l but may be less stringent if higher limit is still protective of environment	• Continuous on-line monitoring of chlorine residual produced oxidant at the compliance monitoring point • For spray irrigation, chlorination levels for disinfection should be continually evaluated to ensure chlorine residual levels do not adversely impact vegetation • Continuous monitoring for turbidity before disinfection is required • Operating		• Not required when another permitted reuse system or effluent disposal system is incorporated into the system design • If system storage ponds are used, they do not have to be lined • Reject storage ponds shall be lined or sealed to prevent measurable seepage • Existing or proposed ponds (such as golf course ponds) are appropriate for storage of reuse water if the ability of the ponds to	• Hydraulic loading rate - maximum annual average of 2 in/wk but may be increased based on a site-specific evaluation • The spray irrigation of reclaimed water shall not produce surface runoff or ponding		• 75 feet to potable water supply wells that are existing or have been approved for construction • 75 feet provided from a reclaimed water transmission facility to all potable water supply wells • 100 feet from outdoor public eating, drinking, and bathing facilities	• Secondary treatment, for the purpose of the manual, refers to the existing treatment requirements in the NJPDES permit, not including the additional reclaimed water for beneficial reuse treatment requirements • A chlorine residual of 0.5 mg/l or greater is recommended to reduce odors, slime, and bacterial re-growth

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• Secondary • Filtration • Chemical addition prior to filtration may be necessary	protocol required • User/Supplier Agreement • Annual usage report		function as stormwater management systems is not impaired				
New Mexico	• Adequately treated and disinfected • Fecal coliform of 1000/100 ml	• Fecal coliform sample taken at point of diversion to irrigation system						• Includes irrigation of freeway landscapes and landscapes in other areas where the public has similar access or exposure
North Carolina	• Tertiary quality effluent (filtered or equivalent) • TSS - 5 mg/l (monthly average) - 10 mg/l (daily maximum) • Fecal coliform - 14/100 ml (monthly geometric mean) - 25/100 ml (daily maximum) • BOD_5 - 10 mg/l (monthly average) - 15 mg/l (daily	• Continuous on-line monitoring and recording for turbidity or particle count and flow prior to discharge	• All essential treatment units to be provided in duplicate • Five-day side-stream detention pond required for effluent exceeding turbidity or fecal coliform limits • Automatically activated standby power source to be provided • Certified operator 24 hours/day with a grade level equivalent to	• Determined using a mass water balance based upon a recent 25-year period using monthly average precipitation data, potential evapotranspiration data, and soil drainage data • No storage facilities required if it can be demonstrated that other permitted disposal options are	• Site specific • Application rate may take both the maximum soil absorption and water needs of the receiving crop into consideration		• 100 feet to any surface waters classified SA, including wetlands • 25 feet to any surface water not classified SA, including wetlands and any swimming pool • 100 feet to any water supply well • 10 feet to any nonpotable well	• Uses include irrigation of golf courses, cemeteries, industrial or commercial site grounds, landscape areas, highway medians, and roadways

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	maximum) • NH_3 - 4 mg/l (monthly average) - 6 mg/l (daily maximum) • Turbidity not to exceed 10 NTU at any time		or greater than the facility classification on call	available				
North Dakota	• At a minimum, secondary treatment • 25 mg/l BOD_5 • 30 mg/l TSS • Fecal coliform - 200/100 ml	• BOD_5 and TSS monitoring once every 2 weeks • Fecal coliform - twice weekly for mechanical plants - once per week for lagoon systems						• Use applies to irrigation of public property such as parks and golf courses • Irrigation should take place during hours when the public does not have access to the area being irrigated
Ohio	• Biological treatment • Disinfection should be considered • 40 mg/l $CBOD_5$ • Fecal coliform (30-day average) - 23/100 ml with no public access buffer - 200/100 ml with 100-foot	*Large system monitoring (150,000 to 500,000 gpd):* • Twice weekly for $CBOD_5$, total coliform (when irrigating) and storage volume • Monthly monitoring for total inorganic nitrogen		• Operational storage of 4 times the daily design flow needed • Storage provisions for at least 130 days of design average flow needed for periods when irrigation is not recommended • Actual storage	• Determined by calculating a water and nutrient balance	• Monitoring wells upgradient and downgradient of large irrigation systems • Monitoring wells should be sampled at the beginning and the end of the irrigation season	• 100 feet to private water well • 300 feet to community water well • 100 feet to sink hole • 50 feet to drainage way • 50 feet to surface water • 100 feet to road right-of-way without	

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	public access buffer - 1,000/100 ml with 200 foot public access buffer • Limits for metals	• Daily monitoring for flow *Small system monitoring (<150,000 gpd):* • Weekly monitoring of CBOD$_5$, total coliform (when irrigating) and storage volume • Daily monitoring of flow		requirements determined by performing water balance • Permits can be obtained for stream discharge during winter and times of high stream flow to reduce storage needs			windbreak using spray irrigation • 10 feet to road right-of-way with windbreak or with flood irrigation • 50 feet to property line	
Oklahoma	• Secondary treatment and disinfection		• Standby power required for continuity of operation during power failures	• Required for periods when available wastewater exceeds design hydraulic loading rate, and when the ground is saturated or frozen • Based on water balance • Must provide at least 90 days of storage above that required for primary treatment	• Based on the lower of the two rates calculated for soil permeability and nitrogen requirements		• 100 feet to adjacent property • Additional distance may be required where prevailing winds could cause aerosols to drift into residential areas • Buffer zone to be a part of the permitted site	• Applies to multi-purpose use areas such as golf courses • Wastewater to be applied during times of non-use • No wastewater applied in public use areas with high potential for skin to ground contact
Oregon	• Level II - biological treatment and disinfection	• Total coliform sampling - 1 time per week	• Standby power with capacity to fully operate all essential				• 10-foot buffer with surface irrigation • 70-foot buffer	• Includes irrigation of golf courses without

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	• Total coliform - 240/100 ml (2 consecutive samples) - 23/100 ml (7-day median)		treatment processes • Redundant treatment facilities and monitoring equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment				with spray irrigation • No spray irrigation within 100 feet of drinking fountains or food preparation areas	contiguous residences, cemeteries, highway medians, and landscapes without frequent public access
South Carolina	• Secondary treatment and disinfection • BOD_5 and TSS - 30 mg/l (monthly average) - 45 mg/l (weekly average) • Total coliform - 200/100 ml (monthly average) - 400/100 ml (daily maximum)	• Nitrate monitoring required			• Hydraulic - maximum of 0.5 - 2 in/wk depending on depth to groundwater • A nitrate to nitrogen loading balance may be required • Application rates in excess of 2 in/wk may be approved provided the application is only for a portion of the year; requires a water balance for the summer season	• Required • One well upgradient • Two wells downgradient • A minimum of 9 wells are suggested for each 18 fairways	• 200 feet to surface waters of the state, occupied buildings, and potable water wells • 75 feet to property boundary	• Applies to irrigation of golf courses

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
South Dakota	• Secondary treatment and disinfection • Total coliform - 200/100 ml (geometric mean)			• Minimum of 210 days capacity without consideration for evaporation	• Maximum application rate limited to 2 in/acre/wk or a total of 24 in/acre/yr	• Shallow wells in all directions of major groundwater flow from site and no more than 200 feet outside of the site perimeter, spaced no more than 500 feet apart, and extending into the groundwater table • Shallow wells within the site are also recommended		
Tennessee	• Biological treatment • Additional treatment requirements are determined on a case-by-case basis • Disinfection required • 30 mg/l BOD_5 and TSS (monthly average) • Fecal coliform - 200/100 ml	• Site specific		• Storage requirements determined by either of two methods, 1) use of water balance calculations or, 2) use of a computer program that was developed based upon an extensive NOAA study of climatic variations throughout the United States	• Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - based on water balance using 5-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 feet to site boundary • 50 feet to onsite streams, ponds, and roads *Spray Irrigation:* [1] Open Fields • 300 feet to site boundary • 150 feet to onsite streams, ponds, and roads [2] Forested • 150 feet to site boundary • 75 feet to onsite streams, ponds, and	• Pertains to irrigation of golf courses, cemeteries, and other public and private land where public use occurs or is expected to occur

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
							roads	
Texas	• Type II reclaimed water *Reclaimed water on a 30-day average to have a quality of:* • 30 mg/l BOD$_5$ with treatment using pond system • 20 mg/l BOD$_5$ or 15 mg/l CBOD$_5$ with treatment other than pond system • Fecal coliform - 200/100 ml (geometric mean) - 800/100 ml (not to exceed in any sample)	• Sampling and analysis once per week for BOD$_5$ or CBOD$_5$ and fecal coliform			• Based on water balance			• Type II reclaimed water use defined as use of reclaimed water where contact between humans and the reclaimed water is unlikely • Uses include irrigation of limited access highway rights-of-way and other areas where human access is restricted or unlikely to occur • Use of reclaimed water for soil compaction and dust control in construction areas where application procedures minimize aerosol drift to public areas also included
Utah	• Type II treated wastewater - secondary	• Weekly composite sampling	• Alternative disposal option or diversion to				• 300 feet to any potable water well	• Uses allowed include irrigation of

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Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	treatment with disinfection • 25 mg/l BOD (monthly average) • TSS - 25 mg/l (monthly average) - 35 mg/l (weekly mean) • Fecal coliform - 200/100 ml (weekly median) - 800/100 ml (not to exceed in any sample) • pH 6 – 9	required for BOD • Daily composite sampling required for TSS • Daily monitoring of fecal coliform • pH monitored continuously or by daily grab samples	storage required in case quality requirements not met				• 300 feet to areas intended for public access • Impoundments at least 500 feet from any potable water well • Public access to effluent storage and irrigation or disposal sites to be restricted by a stocktight fence or other comparable means	highway rights-of-way and other areas where human access is restricted or unlikely to occur • Also allows use of reclaimed water for soil compaction or dust control in construction areas
Washington	• Class C - oxidized and disinfected • Total coliform - 23/100 ml (7-day mean) - 240/100 ml (single sample) *General compliance requirements:* • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples collected at least daily • Continuous on-line monitoring of turbidity	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the irrigation	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the	• Hydraulic loading rate to be determined based on a detailed water balance analysis	• May be required • Monitoring program will be based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics, and other considerations	• 50 feet to areas accessible to the public and use area property line • 100 feet to any potable water supply well	• Uses include irrigation of restricted access areas such as freeway landscapes, or other areas where the public has similar access or exposure to the reclaimed water

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-2. Restricted Urban Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	chlorine residual of 1 mg/l after a contact time of 30 minutes		system is operating	volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted				
Wyoming	• Minimum of Class B wastewater-secondary treatment and disinfection • Fecal coliform - greater than 2.2/100 ml but less than 200/100 ml	• Treated wastewater to be analyzed for fecal coliform, nitrate as N, ammonia as N, and pH at a minimum • Monitoring frequency - once per month for lagoon systems - once per week for mechanical systems • Frequency specified in NPDES permit required if more frequent	• Multiple units and equipment • Alternative power sources • Alarm systems and instrumentation • Operator certification and standby capability • Bypass and dewatering capability • Emergency storage	• Emergency storage	• Will be applied for the purpose of beneficial reuse and will not exceed the irrigation demand of the vegetation at the site • Not to be applied at a rate greater than the agronomic rate for the vegetation at the site • Will be applied in a manner and time that will not cause any surface runoff or contamination of a groundwater aquifer		• 30 feet to adjacent property lines • 30 feet to all surface waters • 100 feet to all potable water supply wells	• Pertains to land that is accessible to the public but with limited access during irrigation periods

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
Arizona	*Class A reclaimed water:* • Secondary treatment, filtration and disinfection • Chemical feed facilities required to add coagulants or polymers if necessary to meet turbidity criterion • Turbidity - 2 NTU (24-hour average) - 5 NTU (not to exceed at any time) • Fecal coliform - none detectable in 4 of last 7 daily samples - 23/100 ml (single sample maximum) *Class B reclaimed water:* • Secondary treatment and disinfection • Fecal coliform - 200/100 ml (not to exceed in 4 of the last 7 daily	• Case-by-case basis			• Application rates based on either the water allotment assigned by the Arizona Department of Water Resources (a water balance that considers consumptive use of water by the crop, turf, or landscape vegetation) or an alternative approved method			• Class A reclaimed water required for spray irrigation of food crops and orchards or vineyards • Class B reclaimed water suitable for surface irrigation of orchards or vineyards

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	samples) - 800/100 ml (single sample maximum)							
Arkansas	• Primary treatment	• As required by regulatory agency		• Based on water balance using divisional average annual 90 percentile rainfall	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l	• Required • One well upgradient • 1 well within site • One well downgradient • More wells may be required on a case-by-case basis	*Spray irrigation:* • 200 feet • 1,320 feet to populated area *Non-spray system:* • 50 feet • 660 feet to populated area	• Pertains to processed food crops only and evaluated on a case-by-case basis • Irrigation of raw food crops is not permitted
California	*Disinfected tertiary recycled water:* • Oxidized, coagulated (not required if membrane filtration is used and/or turbidity requirements are met), filtered, disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day	*Disinfected tertiary recycled water:* • Total coliform - sampled at least once daily from the disinfected effluent • Turbidity - continuously sampled following filtration *Disinfected secondary-2.2 recycled water:* • Total coliform - sampled at least once daily from the disinfected	• Warning alarms • Back-up power source • Multiple treatment units capable of treating entire flow with one unit not in operation or storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of				• No irrigation with disinfected tertiary recycled water within 50 feet of any domestic water supply well unless certain conditions are met • No impoundment of disinfected tertiary recycled water within 100 feet of any domestic water supply well • No irrigation	• Disinfected tertiary recycled water can be used for irrigation of food crops where recycled water comes into contact with edible portion of crop • Disinfected secondary-2.2 recycled water can be used for irrigation of food crops where edible portion is produced above ground and not

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	period) - 240/100 ml (maximum any one sample) • Turbidity requirements for wastewater that has been coagulated and passed through natural undisturbed soils or a bed of filter media - maximum average of 2 NTU within a 24-hour period - not to exceed 5 NTU more than 5 percent of the time within a 24-hour period - maximum of 10 NTU at any time • Turbidity requirements for wastewater passed through membrane - not to exceed 0.2 NTU more than 5 percent of the time within a	effluent	qualified personnel				with, or impoundment of, disinfected secondary-2.2 recycled water within 100 feet of any domestic water supply well • No irrigation with, or impoundment of, undisinfected secondary recycled water within 150 feet of any domestic water supply well • No spray irrigation of any recycled water, other than disinfected tertiary recycled water, within 100 feet of a residence or a place where public exposure could be similar to that of a park, playground, or schoolyard	contacted by the recycled water • Undisinfected secondary recycled water can be used for irrigation of orchards and vineyards where recycled water does not come into contact with edible portion of crop and food crops that must undergo commercial pathogen-destroying processing before consumption

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	24-hour period - maximum of 0.5 NTU at any time *Disinfected secondary-2.2 recycled water:* • Oxidized and disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) *Undisinfected secondary recycled water:* • Oxidized wastewater							
Colorado	*Consumed raw:* [1] Surface irrigation • Oxidized and disinfected • Total coliform - 2.2/100 ml (7-day median) • Not acceptable for root crops or crops where edible portions contact ground [2] Spray						• 500 feet to domestic supply well • 100 feet to any irrigation well • Setback from property lines based upon use of adjoining property	

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	irrigation • Oxidized, coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median) *Processed food:* • Oxidized and disinfected • Total coliform - 23/100 ml (7-day median) *Orchards & Vineyards:* [1] Surface irrigation • Oxidized and disinfected • Total coliform - 23/100 ml (7-day median) • Edible portion of plant cannot contact ground [2] Spray irrigation • Oxidized, coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median)							
Florida	• Secondary	• Parameters to	• Class I	• At a minimum,	• Site specific	• Required	• 75 feet to	• Direct contact

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 20 mg/l $CBOD_5$ (annual average) • 5 mg/l TSS (single sample) • Total chlorine residual of at least 1 mg/l after a minimum acceptable contact time of 15 minutes at peak hourly flow • Fecal coliform - over 30-day period, 75 percent of samples below detection limits - 25/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection	be monitored and sampling frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH, chlorine residual, dissolved oxygen, suspended solids, $CBOD_5$, nutrients, and fecal coliform • Continuous on-line monitoring of turbidity prior to disinfection • Continuous on-line monitoring of total chlorine residual or residual concentrations of other disinfectants • Monitoring for *Giardia* and	reliability - requires multiple or back-up treatment units and a secondary power source • Minimum reject storage capacity equal to 1-day flow at the average daily design flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • Minimum system size of 0.1 mgd (not required for toilet flushing and fire protection uses) • Staffing - 24 hrs/day, 7 days/wk or 6 hrs/day, 7 days/wk with diversion of reclaimed water to reuse	system storage capacity shall be the volume equal to three times the portion of the average daily flow for which no alternative reuse or disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation • Existing or proposed lakes or ponds (such as golf course ponds) are	• Design hydraulic loading rate - maximum annual average of 2 in/wk is recommended • Based on nutrient and water balance assessments	• One upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • One well at the edge of the zone of discharge downgradient of the site (compliance well) • One well downgradient from the site and within the zone of discharge (intermediate well) • One well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific	potable water supply wells • 75 feet from reclaimed water transmission facility to public water supply well • Low trajectory nozzles required within 100 feet of outdoor public eating, drinking, and bathing facilities • 200 feet from unlined storage ponds to potable water supply wells	irrigation of edible crops that will not be peeled, skinned, cooked, or thermally processed before consumption is not allowed except for tobacco and citrus • Indirect application methods that preclude direct contact with the reclaimed water can be used for irrigation of any edible crop • Citrus irrigation systems will only require secondary treatment and basic disinfection if public access will be restricted, the reclaimed water does not directly contact the fruit, and

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
		Cryptosporidium based on treatment plant capacity - ≥ 1 mgd, sampling one time during each two-year period - < 1 mgd , sampling one time during each 5 year period - samples to be taken immediately following disinfection process • Primary and secondary drinking water standards to be monitored by facilities ≥ 100,000 gpd	system only during periods of operator presence	appropriate for storage if it will not impair the ability of the lakes or ponds to function as a stormwater management system • Aquifer storage and recovery allowed as provision of storage		criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for additional parameters based on site-specific conditions and groundwater quality		the fruit produced is processed before human consumption
Hawaii	*R-1 water:* • Oxidized, filtered, and disinfected • Fecal coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in	• Daily flow monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and recording of	• Multiple or standby units required with sufficient capacity to enable effective operation with any one unit out of service • Alarm devices	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary	• Design application rate determined by water balance	• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on	*R-1 water:* • Minimum of 50 feet to drinking water supply well • Outer edge of impoundment at least 100 feet from any drinking water supply well	• R-1 water can be used for spray irrigation of food crops above ground and not contacted by irrigation and orchards and vineyards bearing food

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	any 30-day period) - 200/100 ml (maximum any one sample) • Inactivation and/or removal of 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus • Detectable turbidity not to exceed 5 NTU for more than 15 minutes and never to exceed 10 NTU prior to filtration • Effluent turbidity not to exceed 2 NTU • Chemical pretreatment facilities required in all cases where granular media filtration is used; not required for facilities using membrane	chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of BOD_5 and suspended solids	required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	• Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved		site size, site characteristics, location, method of discharge, and other appropriate considerations • One well upgradient and two wells downgradient for project sites 500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address concerns of public health or environmental	*R-2 water:* • For spray irrigation applications, 500 feet to residence property or a place where public exposure could be similar to that at a park, elementary schoolyard or athletic field • Minimum of 100 feet to any drinking water supply well • Outer edge of impoundment at least 300 feet from any drinking water supply well *R-3 water:* • Minimum of 150 feet to drinking water supply well • Outer edge of impoundment at least 1000 feet to any drinking water supply well	crops • R-2 water can be used for spray irrigation of food crops undergoing commercial pathogen destroying process before consumption, as well as orchards and vineyards not bearing food crops during irrigation • R-2 water can be used for subsurface irrigation of food crops above ground and not contacted by irrigation • R-3 water can be used for drip, surface, or subsurface irrigation of food crops undergoing commercial pathogen process before consumption (no later than

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	filtration • Theoretical chlorine contact time of 120 minutes and actual modal contact time of 90 minutes throughout which the chlorine residual is 5 mg/l *R-2 water:* • Oxidized and disinfected • Fecal coliform - 23/100 ml (7-day median) - 200/100 ml (not to exceed in more than one sample in any 30-day period) • Theoretical chlorine contact time of 15 minutes and actual modal contact time of 10 minutes throughout which the chlorine residual is					protection as related to variable characteristics of the subsurface or of the operations of the project		30 days before before harvest), orchards and vineyards bearing food crops and orchards and vineyards not bearing food crops during irrigation • R-2 water used in spray irrigation will be performed when the area is closed to the public and the public is absent from the area, and will end at least 1 hour before the area is open to the public • Subsurface irrigation may be performed at any time

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	0.5 mg/l *R-3 water:* • Oxidized wastewater							
Idaho	*Raw food crops where reclaimed water contacts edible portion:* • Oxidized, coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median) *Raw food crops where reclaimed water only contacts unedible portion:* • Oxidized and disinfected • Total coliform - 2.2/100 ml (7-day median) *Processed foods and orchards & vineyards with no direct contact of reclaimed water:* [1] Unrestricted public access • Disinfected primary effluent • Total coliform - 230/100 ml							

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	(7-day median) [2] Restricted public access • Primary effluent							
Indiana	• Secondary treatment and disinfection • 10 mg/l BOD_5 • 5 mg/l TSS prior to disinfection (24 hour average) • Fecal coliform - no detectable fecal coliform (7-day median) - 14/100 ml (single sample) • pH 6 - 9 • Total chlorine residual at least 1 mg/l after a minimum contact time of 30 minutes (if chlorination is used for disinfection)	• Daily monitoring of TSS, coliform, and chlorine residual • Weekly monitoring of BOD and pH • Monthly monitoring of total nitrogen, ammonium nitrogen, nitrate nitrogen, phosphorus, and potassium • Annual monitoring of arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc	• Alternate power source required	• Minimum of 90 days effective storage capacity required	• Maximum hydraulic loading rate of 2 in/week		• 200 feet to potable water supply wells or drinking water springs • 300 feet to any waters of the state • 300 feet to any residence	• Food crops not to be harvested for 14 months after land application of wastewater if the harvested part touches the ground and has no harvested parts below the soil surface • Food crops not to be harvested for 38 months after land application of wastewater if harvested parts are below the soil surface • Otherwise, food crops not to be harvested for 30 days after land application of wastewater

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
Kansas	• Secondary treatment with periodic discharge to surface waters • Primary treatment with no discharge to surface water			• Storage provided to retain a minimum of 900 days average dry weather flow when no discharge to surface water is available	• Maximum daily application rate of 3 in/ac/day • Maximum annual application rate of 40 in/acre • Based on soil and crop moisture and/or nutrient requirements of selected crop	• Site specific	• 500 feet to residential areas • 200 feet to wells and water supplies not on site property • 100 feet to adjacent properties • Groundwater table a depth of at least 10 feet beneath application area	• Irrigation of unprocessed food for direct human consumption prohibited
Michigan	• pH 5.5 - 10 • 20 mg/l total inorganic nitrogen • 0.5 mg/l nitrite • 5 mg/l phosphorus • 1 mg/l phosphorus if surface water body is downgradient within 1,000 feet • Aluminum, 150 ug/l • Chloride, 250 mg/l • Sodium, 150 mg/l • Sulfate,	• Flow measurement • Grab samples collected and analyzed twice each month for ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, sodium, chloride, phosphorus, and pH			• Daily, monthly, or annual design hydraulic loading rate shall not be more than 7 percent of the permeability of the most restrictive soil layer within the solum as determined by the saturated hydraulic conductivity method or 12 percent of the permeability as determined by	• May be required • Monitoring requirements specific to each site	• 100 feet to property lines	• Irrigated crops for human consumption shall be limited to those requiring processing prior to consumption • Allows irrigation of vegetated areas between May 1 and October 15 • Governed by Michigan Department of Environmental Quality issued groundwater

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	250 mg/l • Iron, 300 ug/l • Manganese, 50 ug/l • THM limits • Treatment technology standards for certain organic substances • Additional effluent criteria determined on a case-by-case basis				the basin infiltration method • Annual hydraulic loading rate shall not be more than 3 percent of the permeability of the solum when determined by either the cylinder infiltration method or air entry permeameter test method			discharge permits • Categorized as slow rate land treatment
Montana	• Oxidized, clarified, coagulated, filtered, and disinfected • 10 mg/l or less of BOD and TSS • Fecal coliform - 23/100 ml (single sample in any 30-day period) • Turbidity - 2 NTU (average) - 5 NTU (not to exceed more	• Effluent to be monitored on a regular basis to show the biochemical and bacteriological quality of the applied wastewater • Monitoring frequency to be determined on a case-by-case basis			• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013 • Hydraulic loading must be based on the wettest year in ten years	• Determined on a case-by-case basis • Consideration is given to groundwater characteristics, past practices, depth to groundwater, cropping practices, etc.	• 100 feet to any water supply well • Distance to surface water determined on a case-by-case basis based on quality of effluent and the level of disinfection	• Reduction to reclaimed water quality requirements may be considered for food crops which undergo extensive commercial, physical, or chemical processing sufficient to destroy pathogenic agents before it is suitable for

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	than 5 percent of the time during any 24-hour period)							human consumption
Nevada	• At a minimum, secondary treatment with disinfection • 30 mg/l BOD_5 • Fecal coliform - 200/100 ml (30-day geometric mean) - 400/100 ml (maximum daily number)						• None required	• Only surface irrigation of fruit or nut bearing trees permitted
New Jersey	• Fecal coliform - 2.2/100 ml (7-day median) - 14/100 ml (maximum any one sample) • Minimum chlorine residual - 1.0 mg/l after 15-minute contact at peak hourly flow • Alternative methods of disinfection, such as UV and ozone, may be approved • TSS not to	• Continuous on-line monitoring of chlorine residual produced oxidant at the compliance monitoring point • For spray irrigation, chlorination levels for disinfection should be continually evaluated to ensure chlorine residual levels		• Not required when another permitted reuse system or effluent disposal system is incorporated into the system design • If system storage ponds are used, they do not have to be lined • Reject storage ponds shall be lined or sealed to prevent measurable seepage	• Hydraulic loading rate - maximum annual average of 2 in/wk but may be increased based on a site-specific evaluation • The spray irrigation of reclaimed water shall not produce surface runoff or ponding		• 75 feet to potable water supply wells that are existing or have been approved for construction • 75 feet provided from a reclaimed water transmission facility to all potable water supply wells • 100 feet from outdoor public eating, drinking, and bathing	• Irrigation of edible crops that will be peeled, skinned, cooked, or thermally processed before consumption is allowed • An indirect method that precludes direct contact with the reclaimed water (such as ridge and furrow irrigation) is

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	exceed 5 mg/l before disinfection • Total nitrogen - 10 mg/l but may be less stringent if higher limit is still protective of environment • Secondary • Filtration • Chemical addition prior to filtration may be necessary • A chlorine residual of 0.5 mg/l or greater is recommended to reduce odors, slime, and bacterial re-growth	do not adversely impact vegetation • Continuous monitoring for turbidity before disinfection is required • Operating protocol required • User/Supplier Agreement • Annual usage report • Annual inventory submittal on commercial operations using reclaimed water to irrigate edible crop		• Existing or proposed ponds (such as golf course ponds) are appropriate for storage of reuse water if the ability of the ponds to function as stormwater management systems is not impaired			facilities • 100 feet between indoor aesthetic features and adjacent indoor public eating and drinking facilities when in the same room or building	permitted for edible crops that will not be peeled, skinned, cooked, or thermally processed before consumption • Secondary treatment for the purpose of the manual refers to the existing treatment requirements in the NJPDES permit, not including the additional reclaimed water for beneficial reuse treatment requirements
New Mexico	• Adequately treated and disinfected • Fecal coliform – 1,000/100 ml	• Fecal coliform sample taken at point of diversion to irrigation system						• Only surface irrigation on food crops with no contact of reclaimed water on edible portion is permitted
Oklahoma	• Primary treatment		• Standby power required for	• Required for periods when	• Based on the lower of the		• 100 feet to adjacent	• Use not allowed on

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
			continuity of operation during power failures	available wastewater exceeds design hydraulic loading rate, and when the ground is saturated or frozen • Based on water balance • Must provide at least 90 days of storage above that required for primary treatment	two rates calculated for soil permeability and nitrogen requirements		property • Additional distance may be required where prevailing winds could cause aerosols to drift into residential areas • Buffer zone to be a part of the permitted site	food crops that can be eaten raw • May be used for irrigation of crops such as corn, wheat, and oats, provided a period of 30 days elapses between last application and harvest
Oregon	*Unprocessed food :* • Level IV - biological treatment, clarification, coagulation, filtration, and disinfection • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (maximum any sample) • Turbidity - 2 NTU (24-hour mean)	*Unprocessed food:* • Total coliform sampling - once a day • Turbidity - hourly *Processed food crops and orchards and vineyards:* • Total coliform sampling - once a week	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment facilities and monitoring equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure				*Unprocessed food:* • None required *Processed food and orchards and vineyards:* • 10 foot buffer for surface irrigation • 70 foot buffer for spray irrigation	• Surface irrigation required for orchards and vineyards • No irrigation of processed food crops and orchards and vineyards 3 days prior to harvesting

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 5 NTU (5 percent of time during 24-hour period) *Processed food crops and orchards and vineyards:* • Level II - biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) - 23/100 ml (7-day median)		of process equipment					
Texas	*Direct contact with edible portion of crop unless food crop undergoes pasteurization process* • Type I reclaimed water *Reclaimed water on a 30 day average to have a quality of:* • 5 mg/l BOD$_5$ or CBOD$_5$ • 10 mg/l for landscape impoundment • Turbidity	*Direct contact with edible portion of crop unless food crop undergoes pasteurization process* • Sampling and analysis twice per week for BOD$_5$ or CBOD$_5$, turbidity, and fecal coliform *Direct contact with edible portion of crop not likely or where food crop undergoes*			• Based on water balance			• Spray irrigation not permitted on food crops that may be consumed raw • Other types of irrigation that avoid contact of reclaimed water with edible portions of food crops are acceptable • Food crops that will be substantially processed prior to human consumption may be spray

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	- 3 NTU • Fecal coliform - 20/100 ml (geometric mean) - 75/100 ml (not to exceed in any sample) *Direct contact with edible portion of crop not likely or where food crop undergoes pasteurization* • Type II reclaimed water *Reclaimed water on a 30-day average to have a quality of:* • 30 mg/l BOD$_5$ with treatment using pond system • 20 mg/l BOD$_5$ or 15 mg/l CBOD$_5$ with treatment other than pond system • Fecal coliform - 200/100 ml (geometric mean) - 800/100 ml (not to exceed	*pasteurization* • Sampling and analysis once per week for BOD$_5$ or CBOD$_5$ and fecal coliform						irrigated

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	in any sample)							
Utah	*Spray irrigation of food crops:* • Type I treated wastewater - secondary treatment with filtration and disinfection • 10 mg/l BOD (monthly average) • Turbidity prior to disinfection - not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any time • Fecal coliform - none detected (weekly median as determined from daily grab samples) - 14/100 ml (not to exceed in any sample) • 1.0 mg/l total residual chlorine after 30 minutes contact time at peak flow • pH 6 - 9	*Spray irrigation of food crops:* • Daily composite sampling required for BOD • Continuous turbidity monitoring prior to disinfection • Daily monitoring of fecal coliform • Continuous total residual chlorine monitoring • pH monitored continuously or by daily grab samples *Surface irrigation of food crops:* • Weekly composite sampling required for BOD • Daily composite sampling required for TSS • Daily monitoring of	• Alternative disposal option or diversion to storage required in case quality requirements not met				*Spray irrigation of food crops:* • 50 feet to any potable water well • Impoundments at least 500 feet from any potable water well *Surface irrigation of food crops:* • 300 feet to any potable water well • Impoundments at least 500 feet from any potable water well • Public access to effluent storage and irrigation or disposal sites to be restricted by a stocktight fence or other comparable means	• Type I treated wastewater required for spray irrigation of food crops where the applied reclaimed water is likely to have direct contact with the edible part • Type II treated wastewater required for irrigation of food crops where the applied reclaimed water is not likely to have direct contact with the edible part, whether the food will be processed or not (spray irrigation not allowed)

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	Surface irrigation of food crops: • Type II treated wastewater - secondary treatment with disinfection • 25 mg/l BOD (monthly average) • TSS - 25 mg/l (monthly average) - 35 mg/l (weekly mean) • Fecal coliform - 200/100 ml (weekly median) – 800/100 ml (not to exceed in any sample) • pH 6 - 9	fecal coliform • pH monitored continuously or by daily grab samples						
Washington	*Spray irrigation of food crops or surface irrigation of root crops:* • Class A - oxidized, coagulated, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample)	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm,	• Hydraulic loading rate to be determined based on a detailed water balance analysis	• May be required • Monitoring program will be based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics, and other considerations	*Spray irrigation of food crops or surface irrigation of root crops:* • 50 feet to any potable water supply well *Surface irrigation of food crops:* • 50 feet to areas accessible to the public and the use area	• No orchard or vineyard fruit may be harvested that has come in contact with the irrigating water or the ground • Effluent quality requirements for processed food determined on

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	Surface irrigation of food crops: • Class B - oxidized and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) *Irrigation of foods crops that undergo processing or surface irrigation of orchards and vineyards:* • Class D - oxidized and disinfected • Total coliform - 240/100 ml (7-day mean) *General compliance requirements:* • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine	collected at least daily • Continuous on-line monitoring of turbidity	treatment units or storage or disposal options • Qualified personnel available or on call at all times the irrigation system is operating	using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted			property line • 100 feet to any potable water supply *Irrigation of food crops that undergo processing or surface irrigation of orchards and vineyards:* • 100 feet to areas accessible to the public and the use area property line • 300 feet to any potable water supply	a case-by-case basis

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	residual of 1 mg/l after a contact time of 30 minutes							
West Virginia	• Secondary treatment and disinfection • 30 mg/l BOD • 30 mg/l TSS	• Frequency of reporting determined on a case-by-case basis		• Minimum of 90 days storage to be provided	• Hydraulic - maximum application rates of 0.25 in/hr 0.50 in/day 2.0 in/wk	• Minimum of one well between project site and public well(s) or high capacity private wells • Minimum of one well in each direction of groundwater movement	• Fence to be placed at least 50 feet beyond spray area • 350 feet from fence to adjacent property lines or highways unless low trajectory spray and/or physical buffers are provided	• Analysis of crop required if used for human consumption
Wyoming	• Minimum of Class B wastewater - secondary treatment and disinfection • Fecal coliform - greater than 2.2/100 ml but less than 200/100 ml	• Treated wastewater to be analyzed for fecal coliform, nitrate as N, ammonia as N, and pH at a minimum • Monitoring frequency - once per month for lagoon systems - once per week for mechanical systems	• Multiple units and equipment • Alternative power sources • Alarm systems and instrumentation • Operator certification and standby capability • Bypass and dewatering capability • Emergency storage	• Emergency storage	• Will be applied for the purpose of beneficial reuse and will not exceed the irrigation demand of the vegetation at the site • Not to be applied at a rate greater than the agronomic rate for the vegetation at the site • Will be applied in a manner		• 30 feet to adjacent property lines • 30 feet to all surface waters • 100 feet to all potable water supply wells	• Food crops not to be harvested for 30 days after application of treated wastewater

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Table A-3. Agricultural Reuse – Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
		• Frequency specified in NPDES permit required if more frequent			and time that will not cause any surface runoff or contamination of a groundwater aquifer			

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
Alabama	• Minimum EPA secondary, or equivalent to secondary, limits and appropriate disinfection • If wastewater stabilization pond is used, pond must meet ADEM requirements with second cell being used as a holding pond • Mechanical systems, if used, should allow as little nitrification as possible		• Controls required to indicate any system malfunction or permit varied field operations	• Based on water balance performed on a monthly basis with a precipitation input using a 5-year, 24-hour rainfall event, 30-year minimum base period • In addition to storage dictated by water balance, a minimum of 15 days storage should be provided for contingencies	• Based on soil permeability and nitrogen limits (10 mg/l nitrate) • Excessive rainwater run-off should be diverted • Excessive ponding should be avoided	• At least three downgradient monitoring wells • At least one upgradient monitoring well • Contaminants in groundwater not to exceed primary and secondary maximum contaminant levels • Minimum depth to groundwater, without use of an underdrain collection system, shall be 4 feet	• 100 feet to property lines • 300 feet to existing habitable residences • Spray irrigation not allowed within 100 feet of any perennial lake or stream • If irrigation causes an intermittent stream to become perennial, the irrigation must cease within 100 feet of the stream • Spray irrigation not allowed in wellhead protection area (WHPA 1) - if no wellhead delineation exists, minimum distance for application shall be 1,000 feet or as required • No sites within 100 year floodplain	• Categorized as a form of land treatment defined as use of a vegetation-soil system to both renovate and serve as the ultimate receiver of treated wastewater
Alaska	• Secondary							• Categorized as

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	treatment, and if discharge is potential health hazard, disinfection • BOD_5 and TSS from source other than stabilization pond - 30 mg/l (30-day average) - 45 mg/l (7-day average) - 60 mg/l (24-hour average) • BOD_5 from stabilization pond - 45 mg/l (30-day average) and a percent removal that is not less than 65 percent by weight - 65 mg/l (7-day average) • Suspended solids from stabilization pond - 70 mg/l (30-day average) • pH 6 - 9							land surface disposal defined as disposal of treated wastewater onto the surface of the land in area suitable for that purpose

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
Arizona	*Class B reclaimed water:* • Secondary treatment and disinfection • Fecal coliform - 200/100 ml (not to exceed in 4 of the last 7 daily samples) - 800/100 ml (single sample maximum) *Class C reclaimed water:* • Secondary treatment in a series of wastewater stabilization ponds, including aeration, with or without disinfection • Minimum total retention time of 20 days • Fecal coliform - 1,000/100 ml (not to exceed in 4 of the last 7 daily samples) - 4,000/100 ml (single sample maximum)	• Case-by-case basis			• Application rates based on either the water allotment assigned by the Arizona Department of Water Resources (a water balance that considers consumptive use of water by the crop, turf, or landscape vegetation) or an alternative approved method			• Class B reclaimed water may be used for irrigation of pasture for milking animals and livestock watering (dairy animals) • Class C reclaimed water can be used for irrigation of pasture for non-dairy animals; livestock watering (non-dairy animals); irrigation of sod farms, fiber, seed, forage, and similar crops; and silviculture
Arkansas	• Primary treatment • Disinfection			• Based on water balance using divisional	• Hydraulic - 0.5 to 4.0 in/wk • Nitrogen -	• Required • One well upgradient	*Spray irrigation:* • 200 feet • 1,320 feet to	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	also required when irrigating dairy cattle pasture land			average annual 90 percentile rainfall	percolate nitrate-nitrogen not to exceed 10 mg/l	• 1 well within site • One well downgradient • More wells may be required on a case-by-case basis	populated area *Non-spray system:* • 50 feet • 660 feet to populated area	
California	*Ornamental nursery stock and sod farms where access by general public is not restricted, pasture for milking animals, and any nonedible vegetation where access is controlled so that the irrigated area cannot be used as if it were part of a park, playground, or schoolyard* • Disinfected secondary-23 recycled water-oxidized and disinfected • Total coliform - 23/100 ml (7-day median) - 240/100 ml (not to exceed in more than one sample in any 30-day	*Disinfected secondary-23 recycled water* • Total coliform – sampled at least once daily from the disinfected effluent	• Warning alarms • Back-up power source • Multiple treatment units capable of treating entire flow with one unit not in operation or storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of qualified personnel				• No irrigation with, or impoundment of, disinfected secondary-23 recycled water within 100 feet of any domestic water supply well • No irrigation with, or impoundment of, undisinfected secondary recycled water within 150 feet of any domestic water supply well • No spray irrigation within 100 feet of a residence or a place where public exposure could be similar to that of a park, playground, or schoolyard	• Irrigation of ornamental nursery stock and sod farms will be allowed provided no irrigation with recycled water occurs for a period of 14 days prior to harvesting, retail sale, or access by the general public

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	period) *Non food-bearing trees, ornamental nursery stock and sod farms, fodder and fiber crops, pasture for animals not producing milk for human consumption, and seed crops not eaten by humans:* • Undisinfected secondary recycled water-oxidized wastewater							
Colorado	• Oxidized and disinfected • Total coliform - 23/100 ml (7-day median)						• 500 feet to domestic supply well • 100 feet to any irrigation well • Setback from property lines based upon use of adjoining property	• Includes irrigation of pastures for milking animals
Delaware	• Biological treatment and disinfection • BOD_5 - 50 mg/l at average design flow - 75 mg/l at peak flow • TSS	• Parameters which may require monitoring include volume of water applied to spray fields, BOD, suspended		• Storage provisions required either as a separate facility or incorporated into the pretreatment system • Minimum 15	• Maximum design wastewater loadings limited to 2.5 in/week • Maximum instantaneous wastewater application	• Required • One well upgradient of site or otherwise outside the influence of the site for background monitoring	• 150 feet to all property boundaries and the shoulder of internal and external public roads • 100 feet to perennial lake	• Regulations pertain to sites closed to public access

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 50 mg/l for mechanical systems - 90 mg/l for ponds • Fecal coliform - not to exceed 200/100 ml at all times	solids, fecal coliform bacteria, pH, COD, TOC, ammonia nitrogen, nitrate nitrogen, total Kjeldahl nitrogen, total phosphorus, chloride, Na, K, Ca, Mg, metals, and priority pollutants • Parameters and sampling frequency determined on a case-by-case basis		days storage required unless other measures for controlling flow are demonstrated • Must determine operational, wet weather, and water balance storage requirements	rates limited to 0.25 in/hour • Design wastewater loading must be determined as a function of precipitation, evapotranspiration, design percolation rate, nitrogen loading and other constituent loading limitations, groundwater and drainage conditions, and average and peak design wastewater flows and seasonal fluctuations	• One well within wetted field area of each drainage basin intersected by site • Two wells downgradient in each drainage basin intersected by site • One well upgradient and 1 well downgradient of the pond treatment and storage facilities in each drainage basin intersected by site • May require measurement of depth to groundwater, pH, COD, TOC, nitrate nitrogen, total phosphorus, electrical conductivity, chloride, fecal coliform bacteria, metals, and priority pollutants • Parameters	or stream • 50 feet to edge of channelized, intermittent watercourse • If irrigation causes intermittent watercourse to become perennial, 100-foot buffer requirement will apply • Wetland buffers determined on a case-by-case basis	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
						and sampling frequency determined on a case-by-case basis		
Florida	• Secondary treatment and basic disinfection • 20 mg/l $CBOD_5$ and TSS (annual average) • 30 mg/l $CBOD_5$ and TSS (monthly average) • 45 mg/l $CBOD_5$ and TSS (weekly average) • 60 mg/l $CBOD_5$ and TSS (single sample) • 10 mg/l TSS for subsurface application systems (single sample) • Chlorine residual of 0.5 mg/l maintained after at least 15 minutes contact time at peak flow • Fecal coliform - 200/100 ml (annual	• Parameters to be monitored and sampling frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH, chlorine residual, dissolved oxygen, suspended solids, $CBOD_5$, nutrients, and fecal coliform • Primary and secondary drinking water standards to be monitored by facilities $\geq$ 100,000 gpd		• At a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation	• Site specific • Design hydraulic loading rate - maximum annual average of 2 in/wk is recommended • Based on nutrient and water balance assessments	• Required • One upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • One well at the edge of the zone of discharge downgradient of the site (compliance well) • One well downgradient from the site and within the zone of discharge (intermediate well) • Other wells may be required depending on site-specific criteria • Quarterly monitoring	• 100 feet to buildings not part of the treatment facility, utility system, or municipal operation • 100 feet to site property lines • 500 feet to potable water supply wells and Class I and Class II surface waters • 100 feet from reclaimed water transmission facility to public water supply wells • 100 feet to outdoor public eating, drinking, and bathing facilities • 500 feet from new unlined storage ponds to potable water supply wells • Some setback	• Public access will be restricted unless a subsurface application system is used • Reclaimed water may be applied to pastures, wholesale nurseries, sod farms, forests, and areas used to grow feed, fodder, fiber, or seed crops • Milking cows are not permitted to graze on land for a period of 15 days after last application of reclaimed water

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	average) - 200/100 ml (monthly geometric mean) - 400/100 ml (not to exceed in more than 10 percent of samples in a 30-day period) - 800/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection					required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for additional parameters based on site-specific conditions and groundwater quality	distances can be reduced if additional disinfection and reliability are provided or if alternative application techniques are used	
Georgia	• Secondary treatment followed by coagulation, filtration, and disinfection • 5 mg/l BOD • 5 mg/l TSS • Fecal coliform - 23/100 ml (monthly average) - 100/100 ml (maximum any sample) • pH 6 - 9 • Turbidity not to exceed 3 NTU prior to disinfection	• Continuous turbidity monitoring prior to disinfection • Weekly sampling for TSS and BOD • Daily monitoring for fecal coliform • Daily monitoring for pH • Detectable disinfection residual monitoring	• Multiple process units • Ability to isolate and bypass all process units • System must be capable of treating peak flows with the largest unit out of service • Equalization may be required • Back-up power supply • Alarms to warn of loss of power supply,	• Reject water storage equal to at least 3 days of flow at the average daily design flow • One of the following options must be in place to account for wet weather periods - sufficient storage onsite or at the customer's location to handle the			• Determined on a case-by-case basis	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• Detectable disinfectant residual at the delivery point		failure of pumping systems, failure of disinfection systems, or turbidity greater than 3 NTU	flows until irrigation can be resumed - additional land set aside that can be irrigated without causing harm to the cover crop - An NPDES permit for all or part of the flow				
Hawaii	*R-1 water:* • Oxidized, filtered, and disinfected • Fecal coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 200/100 ml (maximum any one sample) • Inactivation and/or removal of 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus • Detectable	• Daily flow monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and recording of chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of BOD_5 and suspended solids	• Multiple or standby units required with sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required	• Design application rate determined by water balance	• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on site size, site characteristics, location, method of discharge, and other appropriate considerations • One well upgradient and two wells downgradient for project sites 500 acres or more • One well within	*R-1 water:* • Minimum of 50 feet to drinking water supply well • Outer edge of impoundment at least 100 feet from any drinking water supply well *R-2 water:* • For spray irrigation applications, 500 feet to residence property or a place where public exposure could be similar to that at a park, elementary school yard or athletic field • Minimum of	• R-1 water can be used for spray irrigation of pastures for milking and other animals • R-2 water can be used with buffer for spray irrigation of sod farms, feed, fodder, fiber, and seed crops not eaten by humans, and timber and trees not bearing food crops • R-2 water can be used for subsurface irrigation of pastures for milking and other animals

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	turbidity not to exceed 5 NTU for more than 15 minutes and never to exceed 10 NTU prior to filtration • Effluent turbidity not to exceed 2 NTU • Chemical pretreatment facilities required in all cases where granular media filtration is used; not required for facilities using membrane filtration • Theoretical chlorine contact time of 120 minutes and actual modal contact time of 90 minutes throughout which the chlorine residual is 5 mg/l *R-2 water:* • Oxidized and disinfected • Fecal coliform - 23/100 ml		source required for treatment plant and distribution pump stations	where an alternate effluent disposal system has been approved		the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address public health concerns or environmental protection as related to variable characteristics of the subsurface or of the operations of the project	100 feet to any drinking water supply well • Outer edge of impoundment at least 300 feet from any drinking water supply well *R-3 water:* • Minimum of 150 feet to drinking water supply well • Outer edge of impoundment at least 1000 feet to any drinking water supply well	• R-2 water can be used for surface, drip, or subsurface irrigation of ornamental plants for commercial use only if plants are harvested above any portion contacted by reclaimed water • R-3 water can be used for drip, surface, or subsurface irrigation of feed, fodder, and fiber crops not eaten by humans and timber and trees not bearing food crops (irrigation must cease at least 24 days before harvest) • R-3 water can be used for drip or surface irrigation of seed crops not eaten by humans • R-2 water

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	(7-day median) - 200/100 ml (not to exceed in more than one sample in any 30-day period) • Theoretical chlorine contact time of 15 minutes and actual modal contact time of 10 minutes throughout which the chlorine residual is 0.5 mg/l *R-3 water:* • Oxidized wastewater							used in spray irrigation will be performed when the area is closed to the public and the public is absent from the area, and will end at least 1 hour before the area is open to the public • Subsurface irrigation may be performed at any time
Idaho	*Unrestricted public access:* • Disinfected primary effluent • Total coliform - 230/100 ml (7-day median) *Restricted public access:* • Primary effluent							• Animals not to be grazed on land where effluent is applied • Animals not to be fed vegetation irrigated with effluent until at least two weeks after application
Illinois	• Two-cell lagoon or mechanical secondary			• Minimum storage capacity equal to at least 150	• Based on the limiting characteristic of the treated	• Required • One well upgradient for determining	• 200 feet to residential lot lines • 25 feet to any	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	treatment			days of wastewater at design average flow except in southern Illinois areas where a minimum 120 days of storage capacity to be provided • Storage can be determined based on a rational design that must include capacity for the wettest year with a 20-year return frequency	wastewater and the site • Balances must be calculated and submitted for water, nitrogen, phosphorus, and BOD	background concentrations • Two wells downgradient in the dominant direction of groundwater movement • Wells between each potable water well and the application area if within 1,000 feet • Monitoring of nitrates, ammonia nitrogen, chlorides, sulfates, pH, total dissolved solids, phosphate, and coliform bacteria	residential lot line if surrounded by a fence with a minimum height of 40 inches • No buffer required if the application and its associated drying time occur during a period when the area is closed to the public	
Indiana	• Secondary treatment and disinfection • 30 mg/l BOD_5 • 30 mg/l TSS • Fecal coliform - 200/100 ml (7-day median) - 800/100 ml (single sample) • pH 6 - 9 • Total chlorine residual at least 1 mg/l after a	• Daily monitoring of TSS, coliform and chlorine residual • Weekly monitoring of BOD and pH • Monthly monitoring of total nitrogen, ammonium nitrogen, nitrate nitrogen,	• Alternate power source required	• Minimum of 90 days effective storage capacity required	• Maximum hydraulic loading rate of 2 in/week		• 200 feet to potable water supply wells or drinking water springs • 300 feet to any waters of the state • 300 feet to any residence	• No restrictions are placed on fecal coliform organisms where public access is strictly restricted • Feed and fiber crops not to be harvested for 30 days after land application of wastewater

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	minimum contact time of 30 minutes (if chlorination is used for disinfection)	phosphorus, and potassium • Annual monitoring of arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc						• Turfgrass not to be harvested for 1 year after application of wastewater • Grazing of animals prohibited for 30 days after land application of wastewater
Iowa	• At a minimum, treatment equivalent to that obtained from a primary lagoon cell • Disinfection - required for all land application systems with spray irrigation application technique - must precede actual spraying of the wastewater on to a field area and must not precede storage - minimum contact time of 15 minutes with equipment necessary to maintain a	• Monitoring of the following parameters required unless it has been demonstrated that they are present in insignificant amounts in the influent wastewater: total organic carbon, total dissolved solids, sodium absorption ratio, electrical conductivity, total nitrogen, ammonia nitrogen, organic nitrogen, nitrate nitrogen, total phosphorus,	• Minimum of two storage cells required capable of series and parallel operation	• Minimum days of storage based on climatic restraints • When flows are generated only during the application period, a storage capacity of 45 days or the flow generated during the period of operation (whichever is less) must be provided • When discharging to a receiving waterway on a periodic basis, storage for 180 days of average wet	• Determined by using a water balance per month of operation • For overland flow systems, maximum hydraulic application rate of 3 in/week	• Monitoring required adjacent to the site both up and downstream of the site in reference to the general groundwater flow direction	• 300 feet to existing dwellings or public use areas (not including roads and highways) • 400 feet to any existing potable water supply well not located on property • 300 feet to any structure, continuous flowing stream or other physiographic feature that may provide direct connection between the groundwater table and the surface • Wetted	• Categorized as land application using slow rate (irrigation) and overland flow

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	residual chlorine level of 0.5 mg/l	chloride, pH, alkalinity, hardness, trace elements, and coliform bacteria • Location of monitoring in effluent prior to site application • Reporting frequency depends on size of system		weather flow is required			disposal area to be at least 50 feet inside the property line of the land application site *Additional requirements for Slow Rate System:* • 1,000 feet to any shallow public water supply well • 500 feet to any public lake or impoundment • _ mile to any public lake or impoundment used as a source of raw water by a potable water supply	
Kansas	• Secondary treatment with periodic discharge to surface waters • Primary treatment with no discharge to surface water			• Storage provided to retain a minimum of 90-days average dry weather flow when no discharge to surface water is available	• Maximum daily application rate of 3 in/ac/day • Maximum annual application rate of 40 in/acre • Based on soil and crop moisture and/or nutrient requirements of selected crop	• Site specific	• 500 feet to residential areas • 200 feet to wells and water supplies off of site property • 100 feet to adjacent properties • Groundwater table a depth of at least 10 feet beneath application	

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
							area	
Maryland	• 70 mg/l BOD • 90 mg/l TSS • pH 6.5 - 8.5 • Fecal coliform - 200/100 ml			• Minimum of 60-days storage to be provided for all systems receiving wastewater flows throughout the year	• Maximum application rate of 2 in/wk on annual average basis • Water balance required based on wettest year in the last 10 years of record • Actual application rate accepted must consider permeability of the soils, depth to groundwater, and the nutrient balance of the site	• May be required • One well upgradient of site • Two wells adjacent to the property line and downgradient of site • Monitoring frequency determined on a case-by-case basis	• 200 feet to property lines, waterways, and roads for spray irrigation • 500 feet to housing developments and parks for spray irrigation • Reduction of the buffer zone up to 50 percent will be considered with adequate windbreak • Minimum buffer zone of 50 feet for all other types of slow rate systems	• Categorized as land treatment
Massachusetts	• Secondary treatment with filtration and disinfection • pH 6 - 9 • 10 mg/l BOD_5 • Turbidity - 2 NTU (average over 24-our period) - 5 NTU (not to exceed at any time) • Fecal coliform - no detectable colonies	• pH - daily • BOD - weekly • Turbidity - continuous monitoring prior to disinfection • Fecal coliform - daily • Disinfection UV intensity - daily or chlorine residual - daily • TSS - twice per week	• EPA Class I Reliability standards may be required • Two independent and separate sources of power • Unit redundancy • Additional storage	• Immediate, permitted discharge alternatives are required for emergency situations and for non-growing season disposal		• Required • Monitoring wells to be located and constructed to strategically sample the geologic units of interest between the discharges and sensitive receptors and withdrawal points • Sensitive	• 100 feet to buildings, residential property, private wells, Class A surface water bodies, and surface water intakes • Other than for private wells, using a green barrier in the form of hedges or trees placed	• Includes use of reclaimed water for landscaping at nurseries • Spray irrigation must take place during non-use hours and cannot result in any ponding

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	(7-day median) - 14/100 ml (single sample) • 5 mg/l TSS • 10 mg/l total nitrogen • Class I groundwater permit standards (SDWA Drinking Water Standards)	• Nitrogen - twice per month • Phosphorus - twice per month • Heterotrophic plate count - quarterly • MS-2 phage - quarterly Permit standards -variable testing requirements				receptors include, but are not limited to public and private wells, surface waters, embayments, and ACECs • Monitoring and testing frequency and parameters determined based on land use, effluent quality and quantity, and the sensitivity of receptors	at the dwelling side of the buffer may reduce the setback distance to 50 feet • No spray irrigation directed into Zone I of public water supply wells	
Michigan	• pH 5.5 - 10 • 20 mg/l total inorganic nitrogen • 0.5 mg/l nitrite • 5 mg/l phosphorus • 1 mg/l phosphorus if surface water body is downgradient within 1,000 feet • Aluminum, 150 ug/l • Chloride, 250 mg/l • Sodium, 150 mg/l • Sulfate, 250 mg/l	• Flow measurement • Grab samples collected and analyzed twice each month for ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, sodium, chloride, phosphorus, and pH			• Daily, monthly, or annual design hydraulic loading rate shall not be more than 7 percent of the permeability of the most restrictive soil layer within the solum as determined by the saturated hydraulic conductivity method or 12 percent of the permeability as determined by the basin	• May be required • Monitoring requirements specific to each site	• 100 feet to property lines	• Dairy animals shall not be allowed to graze on fields until 30 days after the application • Allows irrigation of vegetated areas between May 1 and October 15 • Governed by Michigan Department of Environmental Quality issued groundwater discharge permits • Categorized as

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• Iron, 300 ug/l • Manganese, 50 ug/l • THM limits • Treatment technology standards for certain organic substances • Additional effluent criteria determined on a case-by-case basis				infiltration method • Annual hydraulic loading rate shall not be more than 3 percent of the permeability of the solum when determined by either the cylinder infiltration method or air entry permeameter test method			slow rate land treatment
Missouri	• Treatment equivalent to that obtained from primary wastewater pond cell			• Minimum of 45 days in south with no discharge • Minimum of 90 days in north with no discharge • Based on the design wastewater flows and net rainfall minus evaporation expected for a one in 1--year return frequency for the storage period selected	• Application rates shall in no case exceed - 0.5 in/hour - 1.0 in/day - 3.0 in/week • Maximum annual application rate not to exceed a range from 4 to10 percent of the design sustained permeability rate for the number of days per year when soils are not frozen • Nitrogen	• Minimum of one well between site and public supply well	• 150 feet to existing dwellings or public use areas, excluding roads or highways • 50 feet to property lines • 300 feet to potable water supply wells not on property, sinkholes, and losing streams or other structure or physiographic feature that may provide	• From May 1 to October 30, grazing of animals or harvesting of forage shall be deferred for 14 days after irrigation • From November 1 to April 30, grazing of animals or harvesting of forage shall be deferred for 30 days after irrigation • Grazing of dairy animals generally not

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
					loading not to exceed the amount of nitrogen that can be used by the vegetation to be grown		direct connection between the groundwater table and the surface	recommended unless there has been a much longer deferment period
Montana	*Fodder, fiber, and seed crops:* • Oxidized wastewater • Disinfection generally not required *Pasture for milking animals:* • Oxidized and disinfected • Fecal coliform - 23/100 ml (7-day median)	• Effluent to be monitored on a regular basis to show the biochemical and bacteriological quality of the applied wastewater • Monitoring frequency to be determined on a case-by-case basis			• Nitrogen and hydraulic loadings determined based on methods in EPA Manual 625/1-81-013 • Hydraulic loading must be based on the wettest year in ten years	• Determined on a case-by-case basis • Consideration is given to groundwater characteristics, past practices, depth to groundwater, cropping practices, etc.	• 100 feet to any water supply well • Distance to surface water determined on a case-by-case basis based on quality of effluent and the level of disinfection *Additional requirements for fodder, fiber, and seed crops:* • Fencing must be provided • 200 feet between fencing and irrigated area • 200 feet to any dwelling, including residential property	
Nebraska	• Biological treatment	• Site specific			• Hydraulic loading rate should not exceed 4 in/wk • Nitrogen loading not to	• Site specific		

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
					exceed crop uptake			
Nevada	• Secondary treatment with disinfection • 30 mg/l BOD_5 • Disinfection *Spray irrigation:* *Minimum buffer zone of 400 feet* • Fecal coliform - 200/100 ml (30-day geometric mean) - 400/100 ml (maximum daily number) *Minimum buffer zone of 800 feet* • Fecal coliform - no limit *Surface irrigation:* • Fecal coliform - 200/100 ml (30-day geometric mean) - 400/100 ml (maximum daily number)						*Spray irrigation:* • 400 foot or 800 foot minimum buffer required depending on disinfection level *Surface irrigation*: • None required	• Includes irrigation of land used for pasture or other agricultural purposes except growing crops for human consumption • Public access to site is prohibited
New Jersey	• Fecal coliform - 200/100 ml (monthly average, geometric mean) - 400/100 ml (maximum any one sample)	• Submission of Standard Operations Procedure that ensures proper disinfection to the required level of 1.0 mg/l		• Not required when another permitted reuse system or effluent disposal system is incorporated into the system	• Hydraulic loading rate - maximum annual average of 2 in/wk but may be increased based on a		• 500 feet to potable water supply wells that are existing or have been approved for construction • 100 feet	• Secondary treatment, for the purpose of the manual, refers to the existing treatment requirements in the NJPDES

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• Minimum chlorine residual -1.0 mg/l after 15-minute contact at peak hourly flow • Alternative methods of disinfection, such as UV and ozone, may be approved • TSS - existing treatment requirements as specified in the NJPDES permit for the discharge • Total nitrogen - 10 mg/l but may be less stringent if higher limit is still protective of environment • Secondary	• Chlorination levels should be continually evaluated to ensure the reclaimed water will not adversely impact vegetation • Annual usage report		design • If system storage ponds are used, they do not have to be lined • Reject storage ponds shall be lined or sealed to prevent measurable seepage • Existing or proposed ponds (such as golf course ponds) are appropriate for storage of reuse water if the ability of the ponds to function as stormwater management systems is not impaired	site-specific evaluation • The distribution of reclaimed water shall not produce surface runoff or ponding • Land application sites shall not be frozen or saturated when applying reclaimed water		provided from a reclaimed water transmission facility to all potable water supply wells • 500 feet from FW1 surface waters, Pineland Waters and Shellfish Waters • All other surface water setback distances shall be established on a case-by-case basis • 100 feet from outdoor public eating, drinking, and bathing facilities	permit, not including the additional reclaimed water for beneficial reuse treatment requirements • A chlorine residual of 0.5 mg/l or greater is recommended to reduce odors, slime and bacterial re-growth • For a period of 15 days from the last application of reclaimed water, land application areas shall not be used for the grazing of cattle whose milk is intended for human consumption
New Mexico	*Fodder, fiber, and seed crops:* • Primary effluent *Pastures for milking cows* • Adequately	• Fecal coliform sample taken at point of diversion to irrigation system						

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	disinfected • Fecal coliform - 100/100 ml							
New York	• Secondary treatment and disinfection	• Flow measurement and wastewater characteristics		• Two weeks plus any flow generated in prohibited time period (includes rainfall events)	• Hydraulic - 3 in/wk • Organic - 600 lbs of BOD/acre/day • Maximum salinity - 1,000 mg/l	• Required • Minimum of three off-field wells	• 200 feet to surface waters, dwellings and public roadways	• Spray irrigation should be practiced only from May 1 to November 30 and only during daylight hours • Categorized as land treatment
North Dakota	• If waste stabilization ponds are used - minimum 180 days capacity without consideration for evaporation • Representative sample of reclaimed water must be submitted to determine suitability for irrigation				• Site specific • Based on soils type and type of vegetation • Application rates generally between 0.5 to 4 in/wk			• Areas readily accessible to humans or animals, such as pastures being grazed by dairy animals, hay crops ready for harvesting, or garden crops for human consumption, should not be irrigated
Ohio	• Biological treatment • Disinfection should be considered • 40 mg/l $CBOD_5$ • Fecal coliform (30-day average)	*Large system monitoring (150,000 to 500,000 gpd):* • Twice weekly for $CBOD_5$, total coliform (when irrigating) and storage		• Operational storage of 4 times the daily design flow needed • Storage provisions for at least 130 days of design average flow	• Determined by calculating a water and nutrient balance	• Monitoring wells upgradient and downgradient of large irrigation systems • Monitoring wells should be sampled at	• 100 feet to private water well • 300 feet to community water well • 100 feet to sink hole • 50 feet to drainage way	• Includes agricultural sites where nonhuman food crops are grown

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 23/100 ml with no public access buffer - 1,000/100 ml with 100 foot public access buffer - No disinfection necessary with 200 foot or more public access buffer • Limits for metals	volume • Monthly monitoring for total inorganic nitrogen • Daily monitoring for flow *Small system monitoring: (<150,000 gpd)* • Weekly monitoring of $CBOD_5$ and storage volume • Monthly monitoring of total coliform • Daily monitoring of flow		needed for periods when irrigation is not recommended • Actual storage requirements determined by performing water balance • Permits can be obtained for stream discharge during winter and times of high stream flow to reduce storage needs		the beginning and the end of the irrigation season	• 50 feet to surface water • 100 feet to road right-of-way without windbreak using spray irrigation • 10 feet to road right-of-way with windbreak or with flood irrigation • 50 feet to property line	
Oklahoma	• Primary treatment		• Standby power required for continuity of operation during power failures	• Required for periods when available wastewater exceeds design hydraulic loading rate, and when the ground is saturated or frozen • Based on water balance • Must provide at least 90	• Based on the lower of the two rates calculated for soil permeability and nitrogen requirements		• 100 feet to adjacent property • Additional distance may be required where prevailing winds could cause aerosols to drift into residential areas • Buffer zone to be a part of the permitted site	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
				days of storage above that required for primary treatment				
Oregon	*Pasture for animals, sod, ornamental nursery stock, christmas trees, and firewood* • Level II - biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples) - 23/100 ml (7 day median) *Fodder, fiber, and seed crops not for human ingestion and commercial timber* • Level I - biological treatment	*Pasture for animals, sod, ornamental nursery stock, christmas trees, and firewood* • Total coliform sampling - 1 time per week *Fodder, fiber, and seed crops not for human ingestion and commercial timber* • None required	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment facilities and monitoring equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment				*Pasture for animals, sod, ornamental nursery stock, christmas trees, and firewood* • 10-foot buffer with surface irrigation • 70-foot buffer with spray irrigation *Fodder, fiber, and seed crops not for human ingestion and commercial timber* • 10 foot buffer with surface irrigation • Site specific requirements with spray irrigation	*Pasture for animals, sod, ornamental nursery stock, christmas trees, and firewood* • No animals on pasture during irrigation • No irrigation 3 days prior to harvesting *Fodder, fiber, and seed crops not for human ingestion and commercial timber* • No irrigation for 30 days prior to harvesting • Spray irrigation may be permitted if it can be demonstrated that public health and the environment will be adequately protected from aerosols
Pennsylvania	• Secondary			• Storage	• Hydraulic	• A minimum of		• Categorized as

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	treatment and disinfection • Minimum of 85 percent removal of $CBOD_5$ and TSS • Concentration levels based on a 30-day average - 25 mg/l CBOD5 - 30 mg/l TSS • Fecal coliform - 200/100 ml (monthly geometric average) • pH 6 - 9			requirements determined using daily, weekly, or monthly water balance calculations • Seasonal discharge to surface waters may be an alternative to storage	loading rates based on a water balance that includes precipitation, infiltration rate, evapotranspiration, soil storage capabilities, and subsoil permeability • Application rates both site and waste specific • Application rates greater than 2 in/ac/wk generally not considered	two wells must be located downgradient of the application area		land application of treated sewage • Pertains to slow rate infiltration systems
South Carolina	• Secondary treatment and disinfection • BOD_5 and TSS - 30 mg/l (monthly average) - 45 mg/l (weekly average) • Total coliform - 200/100 ml (monthly average) - 400/100 ml (daily maximum)	• Nitrate monitoring required			• Hydraulic - maximum of 0.5-2 in/wk depending on depth to groundwater • A nitrate to nitrogen loading balance may be required • Application rates in excess of 2 in/wk may be approved provided the application is only for a portion of the	• Required • One well upgradient • Two wells downgradient • At larger sites, more monitoring wells may be required	• 200 feet to surface waters of the state, occupied buildings, and potable water wells • 100 feet to property boundary	

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
					year; requires a water balance for the summer season			
South Dakota	• Secondary treatment			• Minimum of 210 days capacity without consideration for evaporation	• Maximum application rate limited to 2 in/acre/wk or a total of 24 in/acre/yr	• Shallow wells in all directions of major groundwater flow from site and no more than 200 feet outside of the site perimeter, spaced no more than 500 feet apart, and extending into the groundwater table • Shallow wells within the site are also recommended	• 1 mile from municipal water supply • _ mile from private domestic water supply, lakes, and human habitation • _ mile from state parks and recreation areas unless disinfected • 100 feet from neighboring property lines or road right of ways	• Does not include pastures used for dairy grazing
Tennessee	• Biological treatment • Treated to a level afforded by lagoons • Disinfection generally not required, however can be required when deemed necessary	• Site specific		• Storage requirements determined by either of two methods 1) use of water balance calculations or, 2) use of a computer program that was developed based upon an extensive	• Nitrogen - percolate nitrate-nitrogen not to exceed 10 mg/l • Hydraulic - based on water balance using 5-year return monthly precipitation	• Required	*Surface Irrigation:* • 100 feet to site boundary • 50 feet to onsite streams, ponds, and roads *Spray Irrigation:* [1] Open Fields • 300 feet to site boundary • 150 feet to onsite streams, ponds, and	

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
				NOAA study of climatic variations throughout the United States			roads [2] Forested • 150 feet to site boundary • 75 feet to onsite streams, ponds, and roads	
Texas	*Type I reclaimed water:* • 5 mg/l BOD_5 or $CBOD_5$ (30-day average) • 10 mg/l for landscape impoundment (30-day average) • Turbidity - 3 NTU • Fecal coliform - 20/100 ml (geometric mean) - 75/100 ml (not to exceed in any sample) *Type II reclaimed water:* • 30 mg/l BOD_5 with treatment using pond system (30-day average) • 20 mg/l BOD_5 or 15 mg/l $CBOD_5$ with treatment other than pond system (30-day average)	*Type I reclaimed water:* • Sampling and analysis twice per week for BOD_5 or $CBOD_5$, turbidity, and fecal coliform *Type II reclaimed water:* • Sampling and analysis once per week for BOD_5 or $CBOD_5$ and fecal coliform			• Based on water balance			• Type I reclaimed water can be used for irrigation of pastures for milking animals • Type II reclaimed water can be used for irrigation of sod farms, silviculture, and animal feed crops

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	• Fecal coliform - 200/100 ml (geometric mean) - 800/100 ml (not to exceed in any sample)							
Utah	*Type I treated wastewater:* • Secondary treatment with filtration and disinfection • 10 mg/l BOD (monthly average) • Turbidity prior to disinfection - not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any time • Fecal coliform - none detected (weekly median as determined from daily grab samples) - 14/100 ml (not to exceed in any sample) • 1.0 mg/l total residual chlorine after 30 minutes contact time at peak flow	*Type I treated wastewater:* • Daily composite sampling required for BOD • Continuous turbidity monitoring prior to disinfection • Daily monitoring of fecal coliform • Continuous total residual chlorine monitoring • pH monitored continuously or by daily grab samples *Type II treated wastewater:* • Weekly composite sampling required for BOD • Daily composite sampling required for	• Alternative disposal option or diversion to storage required in case quality requirements not met				*Type I treated wastewater:* • 50 feet to any potable water well • Impoundments at least 500 feet from any potable water well *Type II treated wastewater:* • 300 feet to any potable water well • 300 feet to areas intended for public access • Impoundments at least 500 feet from any potable water well • Public access to effluent storage and irrigation or disposal sites to be restricted by a stocktight fence or other comparable means	• Type I reclaimed water can be used for irrigation of pastures for milking animals • Type II reclaimed water can be used for irrigation of sod farms, silviculture, and animal feed crops

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(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• pH 6 - 9 *Type II treated wastewater:* • Secondary treatment with disinfection • 25 mg/l BOD (monthly average) • TSS - 25 mg/l (monthly average) - 35 mg/l (weekly mean) • Fecal coliform - 200/100 ml (weekly median) – 800/100 ml (not to exceed in any sample) • pH 6 - 9	TSS • Daily monitoring of fecal coliform • pH monitored continuously or by daily grab samples						
Vermont	• Minimum of secondary treatment • Tertiary treatment with nitrogen and phosphorus removal can be provided instead of secondary treatment • BOD ≤30 mg/l at any time • TSS ≤30 mg/l at any time • Disinfection with 20 minute		• Multiple units required • Alternative power source required • Retention pond or tank required with volume sufficient to hold the design flow for 48 hours	• Storage sized so that the system can operate effectively without having to spray during the spring runoff months • Minimum storage capacity required - 45 days of design flow	• 2 in/wk for systems with secondary treated effluent • 2.5 in/wk for systems with tertiary treatment with nitrogen and phosphorus removal • Maximum hourly application rate of 0.25 in/hour based on actual wetted area		• 100 feet to edge of any surface water • 200 feet to, habitation, property lines, roads, or areas frequented by the public • 200 feet to any water supply	• Categorized as spray disposal system

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
	chlorine contact time immediately prior to spraying • 1.0 ppm free chlorine residual or 4.0 ppm total chlorine residual at the spray nozzle							
Washington	*Class D:* • Oxidized and disinfected • Total coliform - 240/100 ml (7 day mean) *Class C:* • Oxidized and disinfected • Total coliform - 23/100 ml (7-day mean) - 240/100 ml (single sample) *General compliance requirements:* • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples collected at least daily • Continuous on-line monitoring of turbidity	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the irrigation system is operating	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that portion of the average daily flow for which no alternative reuse or	• Hydraulic loading rate to be determined based on a detailed water balance analysis	• May be required • Monitoring program will be based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics, and other considerations	*Class D:* • 100 feet to areas accessible to the public and the use area property line • 300 feet to any potable water supply *Class C:* • 50 feet to areas accessible to the public and use area property line • 100 feet to any potable water supply well	• Class D reclaimed water can be used for irrigation of trees or fodder, fiber, and seed crops • Class C reclaimed water can be used for irrigation of sod, ornamental plants for commercial use, or pasture to which milking cows or goats have access

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Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	residual of 1 mg/l after a contact time of 30 minutes			disposal system is permitted				
West Virginia	• Secondary treatment and disinfection • 30 mg/l BOD_5 • 30 mg/l TSS	• Frequency of reporting determined on a case-by-case basis		• Minimum of 90 days storage to be provided	• Hydraulic - maximum application rates of 0.25 in/hr 0.50 in/day 2.0 in/wk	• Minimum of one well between project site and public well(s) or high capacity private wells • Minimum of one well in each direction of groundwater movement	• Fence to be placed at least 50 feet beyond spray area • 350 feet from fence to adjacent property lines or highways unless low trajectory spray and/or physical buffers are provided	• Analysis of crop required at harvest if used for animal consumption
Wisconsin	• Biological, chemical, physical or a combination of treatments necessary to meet effluent standards • Monthly average BOD_5 may not exceed 50 mg/l • Fecal coliform bacteria limits based on potential impact to public health • Nitrogen limits based on needs of cover	• Total daily flow monitored • Monthly monitoring for total dissolved solids, chlorides, BOD_5, organic nitrogen, ammonia nitrogen and nitrate plus nitrite nitrogen • Fecal coliform bacteria monitoring may be required on a case-by-case basis • Soil at each		• Storage lagoons required for systems adversely affected by winter conditions or wet weather	• Determined on a case-by-case basis • Based on hydrogeologic conditions, soil texture, permeability, cation exchange capacity, topography, cover crop, and wastewater characteristics • Average hydraulic application rate may not exceed 10,000	• Required for design flows greater than 0.015 mgd • Monitoring may be required for elevation, BOD_5, field specific conductance, COD, organic nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, chlorides, sulfates, total dissolved solids,	• 250 feet to private water supply wells • 1,000 feet to public water supply wells	• Categorized as land disposal

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-4. Agricultural Reuse – Non-Food Crops

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	crop plus demonstrable denitrification	individual spray field tested annually for nitrogen, available phosphorus, available potassium, and pH			gal/acre/day	alkalinity, hardness, temperature, and pH		
Wyoming	• Minimum of Class C wastewater- primary treatment and disinfection • Fecal coliform - 200/100 ml or greater but less than 1000/100 ml	• Treated wastewater to be analyzed for fecal coliform, nitrate as N, ammonia as N, and pH at a minimum • Monitoring frequency - once per month for lagoon systems - once per week for mechanical systems • Frequency specified in NPDES permit required if more frequent	• Multiple units and equipment • Alternative power sources • Alarm systems and instrumentation • Operator certification and standby capability • Bypass and dewatering capability • Emergency storage	• Emergency storage	• Will be applied for the purpose of beneficial reuse and will not exceed the irrigation demand of the vegetation at the site • Not to be applied at a rate greater than the agronomic rate for the vegetation at the site • Will be applied in a manner and time that will not cause any surface runoff or contamination of a groundwater aquifer		• 30 feet to adjacent property lines • 30 feet to all surface waters • 100 feet to all potable water supply wells • 100-foot buffer zone around spray site *Spray Irrigation:* • 100 feet to adjacent property lines and any public right-of-way *Flood Irrigation:* • 30 feet to adjacent property lines and any public right-of-way	• Pertains to irrigation on agricultural lands supporting indirect food chain crops • Animals not allowed to graze on land for 30 days after reclaimed water application

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(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
California	• Disinfected tertiary recycled water that has been subjected to conventional treatment (see monitoring requirements if recycled water has not received conventional treatment) - oxidized, coagulated (not required if membrane filtration is used and/or turbidity requirements are met), clarified, filtered, disinfected • Total coliform measured at a point between the disinfection process and the point of entry to the use impoundment - 2.2/100 ml (7 day median) - 23/100 ml (not to exceed in more than	• Total coliform - sampled at least once daily from the disinfected effluent • Turbidity - continuously sampled following filtration *Monitoring requirements if recycled water has not received conventional treatment:* • Sampled and analyzed monthly for *Giardia*, enteric viruses, and *Cryptosporidium* for first 12 months and quarterly thereafter • Samples to be taken at a point following disinfection and prior to the point where recycled water enters the use impoundment • Ongoing monitoring may be discontinued	• Warning alarms • Back-up power source • Multiple treatment units capable of treating entire flow with one unit not in operation or storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of qualified personnel				• No impoundment of disinfected tertiary recycled water within 100 feet of any domestic water supply well	

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	one sample in any 30-day period) - 240/100 ml (maximum any one sample) • Turbidity requirements for wastewater that has been coagulated and passed through natural undisturbed soils or a bed of filter media - maximum average of 2 NTU within a 24-hour period - not to exceed 5 NTU more than 5 percent of the time within a 24-hour period - maximum of 10 NTU at any time • Turbidity requirements for wastewater passed through membrane - not to exceed 0.2 NTU more than 5 percent of the time within a	after the first 2 years of operation with approval						

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	24-hour period - maximum of 0.5 NTU at any time							
Colorado	• Oxidized, coagulated, clarified, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period)						• 500 feet from impoundment to domestic supply well • 100 feet from impoundment to any irrigation well	
Nevada	• At a minimum, secondary treatment with disinfection • 30 mg/l BOD_5 • Fecal coliform - 2.2/100 ml (30-day geometric mean) - 23/100 ml (maximum daily number)							
Oregon	• Level IV - biological treatment, clarification, coagulation, filtration, and disinfection • Total coliform	• Total coliform sampling - 1/day • Turbidity - hourly	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment					

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	- 2.2/100 ml (7-day median) - 23/100 ml (maximum any sample) • Turbidity - 2 NTU (24-hour mean) - 5 NTU (5 percent of time during 24-hour period)		facilities and monitoring equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment					
Texas	• Type I reclaimed water *Reclaimed water on a 30 day average to have a quality of:* • 5 mg/l BOD$_5$ or CBOD$_5$ • Turbidity - 3 NTU • Fecal coliform - 20/100 ml (geometric mean) - 75/100 ml (not to exceed in any sample)	• Sampling and analysis twice per week for BOD$_5$ or CBOD$_5$, turbidity, and fecal coliform						
Utah	• Type I treated wastewater - secondary treatment with filtration, and disinfection • 10 mg/l BOD (monthly average)	• Daily composite sampling required for BOD • Continuous turbidity monitoring prior to	• Alternative disposal option or diversion to storage required if turbidity or chlorine residual requirements				• Impoundments at least 500 feet from any potable water well	

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• Turbidity prior to disinfection - not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any time • Fecal coliform - none detected (weekly median as determined from daily grab samples) - 14/100 ml (not to exceed in any sample) • 1.0 mg/l total residual chlorine after 30 minutes contact time at peak flow • pH 6 - 9	disinfection • Daily monitoring of fecal coliform • Continuous total residual chlorine monitoring • pH monitored continuously or by daily grab samples	not met					
Washington	• Class A - oxidized, coagulated, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) • 30 mg/l BOD and TSS (monthly	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a		• May be required • Monitoring will be based on reclaimed water quality and quantity, site-specific soil and hydrogeologic characteristics, and other considerations	• Unlined impoundments - 500 feet between perimeter and any potable water supply well • Lined impoundments - 100 feet between perimeter and	• Nutrient removal to reduce levels of phosphorus and/or nitrogen is recommended to minimize algal growths and maintain acceptable aesthetic conditions

Table A-5. Unrestricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes	- grab samples collected at least daily • Continuous on-line monitoring of turbidity	treatment units or storage or disposal options • Qualified personnel available or on call at all times the irrigation system is operating	10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted			any potable water supply well	

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
Arizona	• Class A reclaimed water-secondary treatment, filtration, and disinfection • Chemical feed facilities required to add coagulants or polymers if necessary to meet turbidity criterion • Turbidity - 2 NTU (24 hour average) - 5 NTU (not to exceed at any time) • Fecal coliform - none detectable in 4 of last 7 daily samples - 23/100 ml (single sample maximum)	• Case-by-case basis						
California	• Disinfected secondary-2.2 recycled water-oxidized and disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than	• Total coliform - sampled at least once daily from the disinfected effluent	• Warning alarms • Back-up power source • Multiple treatment units capable of treating entire flow with one unit not in operation or				• No impoundment of disinfected secondary-2.2 recycled water within 100 feet of any domestic water supply well	• Includes any publicly accessible impoundments at fish hatcheries

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	one sample in any 30-day period)		storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of qualified personnel					
Colorado	• Oxidized and disinfected • Total coliform - 2.2/100 ml (7-day median)						• 500 feet from impoundment to domestic supply well • 100 feet from impoundment to any irrigation well	
Hawaii	• R-1 water- oxidized, filtered, and disinfected • Fecal coliform – 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 200/100 ml (maximum any one sample) • Inactivation and/or removal	• Daily flow monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and recording of chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of	• Multiple or standby units required of sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30 year record • Reject storage			• Outer edge of impoundment at least 100 feet from any drinking water supply well	

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	of 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus • Effluent turbidity not to exceed 2 NTU • Chemical pretreatment facilities required in all cases where granular media filtration is used; not required for facilities using membrane filtration • Theoretical chlorine contact time of 120 minutes and actual modal contact time of 90 minutes throughout which the chlorine residual is 5 mg/l	BOD$_5$ and suspended solids	filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved				
Nevada	• At a minimum, secondary treatment with disinfection							• Pertains to impoundments where full body contact with

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• 30 mg/l BOD_5 • Fecal coliform - 2.2/100 ml (30 day geometric mean) - 23/100 ml (maximum daily number)							the treated effluent cannot reasonably be expected
Oregon	• Level III - biological treatment and disinfection • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (maximum any sample)	• Total coliform sampling - 3/week	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment facilities and monitoring equipment to meet required levels of treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment					
Texas	• Type II reclaimed water *Reclaimed water on a 30-day average to have a quality of:* • 30 mg/l BOD_5 with treatment using pond	• Sampling and analysis once per week for BOD_5 or $CBOD_5$ and fecal coliform						

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	system • 20 mg/l BOD$_5$ or 15 mg/l CBOD$_5$ with treatment other than pond system • Fecal coliform - 200/100 ml (geometric mean) - 800/100 ml (not to exceed in any sample)							
Utah	• Type II treated wastewater - secondary treatment with disinfection • 25 mg/l BOD (monthly average) • TSS - 25 mg/l (monthly average) - 35 mg/l (weekly mean) • Fecal coliform - 200/100 ml (weekly median) – 800/100 ml (not to exceed in any sample) • pH 6 - 9	• Weekly composite sampling required for BOD • Daily composite sampling required for TSS • Daily monitoring of fecal coliform • pH monitored continuously or by daily grab samples	• Alternative disposal option or diversion to storage required in case quality requirements not met				• Impoundments at least 500 feet from any potable water well	
Washington	• Class B - oxidized and disinfected • Total coliform	• BOD – 24-hour composite samples collected at	• Warning alarms independent of normal power	• Storage required when no approved alternative		• May be required • Monitoring program will be	• Unlined impoundments - 500 feet between	• Nutrient removal to reduce levels of phosphorus

Table A-6. Restricted Recreational Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	- 2.2/100 ml (7-day mean) - 23/100 ml (single sample) • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes	least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples collected at least daily • Continuous on-line monitoring of turbidity	supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the irrigation system is operating	disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to three times that portion of the average daily flow for which no alternative reuse or disposal system is permitted		based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics, and other considerations	perimeter and any potable water supply well • Lined impoundments - 100 feet between perimeter and any potable water supply well	and/or nitrogen is recommended to minimize algal growths and maintain acceptable aesthetic conditions

Table A-7. Environmental – Wetlands

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
Florida	*Treatment wetland:* • Secondary treatment with nitrification • 20 mg/l $CBOD_5$ and TSS (annual average) • 2 mg/l total ammonia (monthly average) *Receiving wetland:* • 5 mg/l $CBOD_5$ and TSS (annual average) • 3 mg/l total nitrogen (annual average) • 1 mg/l total phosphorus (annual average) • 2 mg/l total ammonia (monthly average)			• Reclaimed water shall be stored in a holding pond • The holding pond will have sufficient storage capacity to assure retention of reclaimed water that has not been treated to an acceptable quality for discharge to a treatment or receiving wetland • At a minimum, this capacity will be the volume equal to 1 day of flow at the permitted capacity of the treatment plant	• Maximum annual average hydraulic loading of 2 in/wk except in hydrologically altered wetlands - maximum of 6 in/wk • Treatment wetland - total nitrogen loading rate not to exceed 25 $g/m^2/yr$ - total phosphorus loading rate not to exceed 3 $g/m^2/yr$ • Hydrologically altered wetland - total nitrogen loading rate not to exceed 75 $g/m^2/yr$ - total phosphorus loading rate not to exceed 9 $g/m^2/yr$			• The discharge of reclaimed water to treatment or receiving wetlands shall minimize channelized flow and maximize sheet flow in the wetland, minimize the loss of dissolution of sediments due to erosion or leaching, and not cause adverse effects on endangered or threatened species • Discharge of reclaimed water to wetlands located within Class I surface waters considered reuse for indirect potable purposes
South Dakota	• Pretreatment with stabilization ponds			• Minimum recommended storage capacity in stabilization	• Maximum hydraulic design loading flow through rate on artificial	• A minimum of three wells, one upgradient and two downgradient	• The entire wetland area to be enclosed with a suitable fence to	• Applies to artificial wetland systems • Reviewed on a

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-7. Environmental – Wetlands

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
				pond system of 150 days • Minimum combined storage capacity of 180 days in stabilization ponds and artificial wetland areas	wetlands of 25,000 gal/acre/day	of the site, may be required • At a minimum, parameters to be sampled include temperature, pH, conductivity, nitrate, ammonia, fecal coliform, nitrites, chlorides, TDS, sulfate, and GW elevations	provide public safety, exclude livestock, and discourage trespassing	site-by-site basis
Washington	*Natural and constructed beneficial use wetlands that provide potential human contact, recreational, or educational beneficial uses:* • Class A - oxidized, coagulated, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) *Natural and constructed beneficial use*	• BOD, TSS, Kjeldahl nitrogen, ammonia-nitrogen, total phosphorus, and metals - 24-hour composite samples collected weekly • Total coliform - grab samples collected at least daily • Continuous flow monitoring	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the	• Not to exceed an additional average annual hydraulic loading rate of 2 cm/day to Category II wetlands and 3 cm/day to Category III and IV wetlands • Maximum annual average hydraulic loading rate to constructed beneficial use wetlands is limited to	• May be required • Groundwater monitoring may be required for a sufficient length of time to determine that the application of reclaimed water will not degrade existing groundwater quality • Depends on parameter concentrations in reclaimed water and the	• Unlined or unsealed wetland - 500 feet between perimeter and any potable water supply well • Lined or sealed wetland - 100 feet between perimeter and any potable water supply well	• Discharge to Category I wetlands or to saltwater dominated wetlands is not permitted • Reclaimed water intended for beneficial reuse may be discharged for streamflow augmentation provided the reclaimed water meets certain requirements

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Table A-7. Environmental – Wetlands

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	wetlands that provide fisheries, or potential human non-contact recreational or educational beneficial uses: • Class B - oxidized and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) *Natural wetlands that provide potential non-contact recreational or educational beneficial uses through restricted access* • Class C - oxidized and disinfected • Total coliform - 23/100 ml (7-day mean) - 240/100 ml (single sample) *General compliance requirements:* • 20 mg/l BOD and TSS (average annual basis)		the irrigation system is operating	volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted	5 cm/day • Hydraulic loading rate determined as the ratio of the average annual flow rate of reclaimed water to the effective wetted area of the wetland	groundwater quality criteria		

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-7. Environmental – Wetlands

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	• 3 mg/l total Kjeldahl nitrogen (average annual basis) • Total ammonia nitrogen not to exceed Washington chronic standards for freshwater • 1 mg/l total phosporus (average annual basis) • Metals not to exceed Washington surface water quality standards							

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Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [1]	Other
California	*Cooling water that creates a mist:* • Disinfected tertiary recycled water -oxidized, coagulated (not required if membrane filtration is used and/or turbidity requirements are met), filtered, disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 240/100 ml (maximum any one sample) • Turbidity requirements for wastewater that has been coagulated and passed through natural undisturbed soils or a bed of filter media - maximum average of 2 NTU within a 24-hour period - not to exceed 5 NTU more	*Cooling water that creates a mist:* • Total coliform - sampled at least once daily from the disinfected effluent • Turbidity - continuously sampled following filtration *Cooling water that does not create a mist:* • Total coliform - sampled at least once daily from the disinfected effluent	• Warning alarms • Back-up power source • Multiple treatment units capable of treating entire flow with one unit not in operation or storage or disposal provisions • Emergency storage or disposal: short-term, 1 day; long-term, 20 days • Sufficient number of qualified personnel					• Whenever a cooling system, using recycled water in conjunction with an air conditioning facility, uses a cooling tower or otherwise creates a mist that could come into contact with employees or members of the public, the cooling system shall comply with the following: - a drift eliminator shall be used whenever the cooling system is in operation - a chlorine, or other biocide, shall be used to treat the cooling system recirculating water to minimize the growth of *Legionella* and other micro-organisms • Reclaimed water can also

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	than 5 percent of the time within a 24-hour period - maximum of 10 NTU at any time • Turbidity requirements for wastewater passed through membrane - not to exceed 0.2 NTU more than 5 percent of the time within a 24-hour period - maximum of 0.5 NTU at any time *Cooling water that does not create a mist:* • Disinfected secondary-23 recycled water-oxidized and disinfected • Total coliform - 23/100 ml (7-day median) - 240/100 ml (not to exceed in more than one sample in any 30-day period)							be used for industrial boiler feed and industrial process water
Florida	*Once-through cooling water and*	*Once-through cooling water,*	*Open cooling water tower*	*Once-through cooling water,*			*Once-through cooling water,*	• Allows use of reclaimed

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(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	process water at wastewater treatment plants: • Secondary treatment • 20 mg/l $CBOD_5$ and TSS (annual average) • 30 mg/l $CBOD_5$ and TSS (monthly average) • 45 mg/l $CBOD_5$ and TSS (weekly average) • 60 mg/l $CBOD_5$ and TSS (single sample) • pH 6 - 8.5 *Wash water or process water:* • Secondary treatment and basic disinfection • 20 mg/l $CBOD_5$ and TSS (annual average) • 30 mg/l $CBOD_5$ and TSS (monthly average) • 45 mg/l $CBOD_5$ and TSS (weekly average) • 60 mg/l $CBOD_5$ and TSS	*wash water or process water:* • Parameters to be monitored and sampling frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH, chlorine residual, dissolved oxygen, suspended solids, $CBOD_5$, nutrients, and fecal coliform • Primary and secondary drinking water standards to be monitored by facilities ≥ 100,000 gpd *Open cooling water tower applications:* • Parameters to be monitored and sampling frequency to be identified in wastewater	*applications:* • Class I reliability - requires multiple or back-up treatment units and a secondary power source • Minimum reject storage capacity equal to 1 day flow at the average daily design flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • Minimum system size of 0.1 mgd (not required for toilet flushing and fire protection uses) • Staffing - 24 hrs/day, 7 days/wk or 6 hrs/day, 7 days/wk with diversion of reclaimed water to reuse system only	*wash water or process water:* • System storage ponds not required *Open cooling water tower applications:* • At a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility			*wash water or process water:* • Setback distances from the industrial process or activity to the site property line not required *Open cooling water tower applications:* • None required if the reclaimed water has received secondary treatment with filtration and high-level disinfection • 300-foot setback distance provided from the cooling tower to the site property lines if reclaimed water has received secondary treatment and basic disinfection	water for cooling water, wash water, or process water at industrial facilities • Reclaimed water that has not been disinfected may be used for once-through cooling purposes at industrial facilities if the reclaimed water has received at least secondary treatment, is conveyed and used in closed systems which are not open to the atmosphere, and is returned to the domestic wastewater treatment facility • Reclaimed water that has received secondary treatment and basic disinfection

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances [(1)]	Other
	(single sample) • Chlorine residual of 0.5 mg/l maintained after at least 15 minutes contact time at peak flow • Fecal coliform - 200/100 ml (annual average) - 200/100 ml (monthly geometric mean) - 400/100 ml (not to exceed in more than 10 percent of samples in a 30-day period) - 800/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection *Open cooling water tower applications:* • Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 20 mg/l CBOD$_5$	facility permit • Minimum schedule for sampling and testing based on system capacity established for flow, pH, chlorine residual, dissolved oxygen, suspended solids, CBOD$_5$, nutrients, and fecal coliform • Continuous on-line monitoring of turbidity prior to disinfection • Continuous on-line monitoring of total chlorine residual or residual concentrations of other disinfectants • Monitoring for *Giardia* and *Cryptosporidium* - sampling one time during each 2 year period - samples to be taken immediately	during periods of operator presence	operation				can be used in open cooling towers if a 300-foot setback distance is provided to the property line, the cooling tower is designed and operated to minimize aerosol drift to areas beyond the site property line that are accessible to the public, and biological growth is controlled

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	(annual average) • 5 mg/l TSS (single sample) to be met after filtration and prior to disinfection • Total chlorine residual of at least 1 mg/l after a minimum acceptable contact time of 15 minutes at peak hourly flow • Fecal coliform - over 30-day period, 75 percent of samples below detection limits - 25/100 ml (single sample) • pH 6 - 8.5 • Limitations to be met after disinfection	following disinfection process • Primary and secondary drinking water standards to be monitored by facilities ≥ 100,000 gpd						
Hawaii	*Cooling water that emits vapor or droplets or an industrial process with exposure to workers:* • R-1 water- oxidized, filtered, and disinfected	• Daily flow monitoring • Continuous turbidity monitoring prior to and after filtration process • Continuous measuring and	• Multiple or standby units required of sufficient capacity to enable effective operation with any one unit out of service	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage				• Can be used for industrial cooling in a system that does not have a cooling tower, evaporative condenser, or other feature

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances $^{(1)}$	Other
	• Fecal coliform - 2.2/100 ml (7-day median) - 23/100 ml (not to exceed in more than one sample in any 30-day period) - 200/100 ml (maximum any one sample) • Inactivation and/or removal of 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus • Effluent turbidity not to exceed 2 NTU • Chemical pretreatment facilities required in all cases where granular media filtration is used; not required for facilities using membrane filtration • Theoretical chlorine contact time of 120 minutes and actual modal	recording of chlorine residual • Daily monitoring of fecal coliform • Weekly monitoring of BOD_5 and suspended solids	• Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	is necessary • Storage requirements based on water balance using at least a 30 year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved				that emits vapor or droplets to the open atmosphere or to air to be passed into a building or other enclosure occupied by a person • Can be used as supply for addition to a cooling system or air conditioning system with a cooling tower, evaporative condenser, or other feature that emits vapor or droplets to the open atmosphere or to air to be passed into a building or other enclosure occupied by a person, when all of the following occurs: a high efficiency drift reducer is used and the

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	contact time of 90 minutes throughout which the chlorine residual is 5 mg/l *Cooling water that does not emit vapor or droplets, an industrial process without exposure to workers or industrial boiler feed:* • R-2 water-oxidized and disinfected • Fecal coliform - 23/100 ml (7-day median) - 200/100 ml (not to exceed in more than one sample in any 30-day period) • Theoretical chlorine contact time of 15 minutes and actual modal contact time of 10 minutes throughout which the chlorine residual is 0.5 mg/l							system is maintained to avoid greater rate of generation of drift than that which a high efficiency drift reducer is associated; a continuous biocide residual, sufficient to prevent bacterial population from exceeding 10,000/ml is maintained in circulating water; and the system is inspected by an operator capable of determining compliance at least once per day

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
New Jersey	• Requires a case-by-case review • Fecal coliform - 200/100 ml (monthly average, geometric mean) - 400/100 ml (maximum any one sample • Minimum chlorine residual - 1.0 mg/l after 15 minute contact at peak hourly flow • TSS requirements applies to the existing treatment requirements as specified in the NJPDES permit for the discharge • Secondary	• Submission of Standard Operations Procedure that ensures proper disinfection to the required level of 1.0 mg/l • Annual usage report		• Not required when another permitted reuse system or effluent disposal system is incorporated into the system design • If system storage ponds are used, they do not have to be lined • Reject storage ponds shall be lined or sealed to prevent measurable seepage • Existing or proposed ponds (such as golf course ponds) are appropriate for storage of reuse water if the ability of the ponds to function as stormwater management systems is not impaired				• Worker contact with reclaimed water shall be minimized • Windblown spray shall not reach areas accessible to the public • Secondary treatment, for the purpose of the manual, refers to the existing treatment requirements in the NJPDES permit, not including the additional reclaimed water for beneficial reuse treatment requirements
North Carolina	• Tertiary quality effluent (filtered or equivalent) • TSS	• Continuous on-line monitoring and recording for	• All essential treatment units to be provided in duplicate	• Determined using a mass water balance based upon a				• Includes reclaimed water used for process water

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Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 5 mg/l (monthly average) - 10 mg/l (daily maximum) • Fecal coliform - 14/100 ml (monthly geometric mean) - 25/100 ml (daily maximum) • BOD$_5$ - 10 mg/l (monthly average) - 15 mg/l (daily maximum) • NH$_3$ - 4 mg/l (monthly average) - 6 mg/l (daily maximum) • Turbidity not to exceed 10 NTU at any time	turbidity or particle count and flow prior to discharge	• Five-day side stream detention pond required for effluent exceeding turbidity or fecal coliform limits • Automatically activated standby power source to be provided • Certified operator on call 24 hrs/day with a grade level equivalent to or greater than the facility classification	recent 25-year period using monthly average precipitation data, potential evapotrans-piration,data, and soil drainage data • No storage facilities required if it can be demonstrated that other permitted disposal options are available				and cooling water purposes
Oregon	• Level II is minimum treatment for industrial or commercial uses - biological treatment and disinfection • Total coliform - 240/100 ml (2 consecutive samples)	• Total coliform sampling - Once a week	• Standby power with capacity to fully operate all essential treatment processes • Redundant treatment facilities and monitoring equipment to meet required levels of					• Use of reclaimed water in evaporative cooling systems will be approved only if the user can demonstrate that aerosols will not present a hazard to public health

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 23/100 ml (7-day median)		treatment • Alarm devices to provide warning of loss of power and/or failure of process equipment					
Texas	*Cooling tower makeup water* • Type II reclaimed water *Reclaimed water on a 3- day average to have a quality of:* • 30 mg/l BOD_5 with treatment using pond system • 20 mg/l BOD_5 or 15 mg/l $CBOD_5$ with treatment other than pond system • Fecal coliform - 200/100 ml (geometric mean) - 800/100 ml (not to exceed in any sample)	• Sampling and analysis once per week for BOD_5 or $CBOD_5$ and fecal coliform						• Use for cooling towers which produce significant aerosols adjacent to public access areas may have special requirements

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Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
Utah	*Cooling water:* • Type II treated wastewater - secondary treatment with disinfection • 25 mg/l BOD (monthly average) • TSS - 25 mg/l (monthly average) - 35 mg/l (weekly average) • Fecal coliform - 200/100 ml (weekly median) - 800/100 ml (not to exceed in any sample) • pH 6 - 9	• Weekly composite sampling required for BOD • Daily composite sampling required for TSS • Daily monitoring of fecal coliform • pH monitored continuously or by daily grab samples	• Alternative disposal option or diversion to storage required in case quality requirements not met					• Use for cooling towers which produce aerosols in populated areas may have special restrictions imposed
Washington	*Industrial boiler feed, industrial cooling water where aerosols or other mists are not created, and industrial process water with no exposure to workers:* • Class C - oxidized and disinfected • Total coliform - 23/100 ml (7-day mean)	• BOD – 24-hour composite samples collected at least weekly • TSS – 24-hour composite samples collected at least daily • Total coliform and dissolved oxygen - grab samples collected at	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20				

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Table A-8. Industrial Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances (1)	Other
	- 240/100 ml (single sample) *Industrial cooling water where aerosols or other mists are created and industrial process water with exposure to workers:* • Class A - oxidized, coagulated, filtered, and disinfected • Total coliform - 2.2/100 ml (7-day mean) - 23/100 ml (single sample) *General compliance requirements:* • 30 mg/l BOD and TSS (monthly mean) • Turbidity - 2 NTU (monthly) - 5 NTU (not to exceed at any time) • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes	least daily • Continuous on-line monitoring of turbidity	disposal options • Qualified personnel available or on call at all times the irrigation system is operating	years of climatic data • At a minimum, system storage capacity should be equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted				

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
California	• Determined on a case-by-case basis • Based on all relevant aspects of each project, including the following factors: treatment provided; effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time and distance to withdrawal							
Florida	*Use of rapid-rate land application systems:* • Secondary treatment and basic disinfection • Fecal coliform - 200/100 ml (annual average) - 200/100 ml (monthly geometric mean) - 400/100 ml (not to exceed	• Continuous on-line monitoring for turbidity before applicaton of the disinfectant • Continuous monitoring for chlorine residual or for residual concentrations of other disinfectants • Treatment facilities designed to	• Class I reliability - requires multiple or backup treatment units and a secondary power source • For treatment facilities required to provide full treatment and disinfection - minimum reject storage	• System storage not required • If system storage is provided, at a minimum, system storage capacity shall be the volume equal to three times the portion of the average daily flow for which no alternative reuse or	• Reasonable assurances must be provided that the hydraulic loading rates used in the design must enable the system to comply with the requirements while meeting applicable groundwater quality	• Required • 1 upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • 1 well at the edge of the zone of discharge down-gradient of the site	• Zones of discharge not to extend closer than 500 feet to a potable water supply well • 1,000 foot setback distance from injection well used for salinity barrier control to potable water supply wells • 500 feet to	• Rapid-rate application systems that result in the collection and discharge of more than 50 percent of the applied reclaimed water will be considered effluent disposal systems • Involves the planned use of

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	in more than 10% of samples in a 30 day period) - 800/100 ml (single sample) • 10 mg/l TSS (single sample) prior to discharge to the application/ distribution system for absorption field systems • Nitrate - 12 mg/l as nitrogen *Use of rapid-rate land application systems for projects considered reuse for groundwater recharge under 62-610.525:* • Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 5 mg/l TSS (single sample) to be achieved prior to	meet the full treatment and disinfection requirements to sample for TOC and total organic halogen daily, seven days per week • Total coliforms and TSS analyzed daily if treatment facility is required to meet bacteriological requirements of the drinking water standards • Parameters listed as primary drinking water standards that are imposed as reclaimed water limits to be analyzed monthly • Parameters listed as secondary drinking water standards that are imposed	capacity equal to three day's flow at the average daily permitted flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • If full treatment and disinfection is not required, the capacity requirement for reject storage shall be reduced to one day's flow • Reject storage will not be required if another permitted reuse system or effluent disposal system is capable of discharging the reject water in accordance with	disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation	standards • A groundwater mounding analysis is to be included in the engineering report and should provide reasonable assurances that the proposed project will function as intended and will not result in excessive mounding of groundwaters, increases in surface water elevations, property damage or interference with reasonable use of property within the affected area	(compliance well) • 1 well downgradient from the site and within the zone of discharge (intermediate well) • 1 well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH and sulfate • Monitoring may be required for additional	potable water supply wells that are existing or have been approved; Class I surface waters; or Class II surface waters • Setback distance to Class I and Class II surface waters reduced to 100 feet if high-level disinfection is provided • 100 feet to buildings not part of the treatment facility, utilities system or municipal operations • 100 feet to site property line • Some setback distances may be reduced if certain treatment requirements are met and assurances	reclaimed water to augment Class F-1, G-1, or G-II groundwaters identified for potable water use and defined as groundwater recharge in regulations • Types of groundwater recharge systems include injection of reclaimed water into Class F-1, G-1, or G-II groundwaters, specific rapid-rate land application systems, use of reclaimed water to create barriers to the landward or upward migration of salt water within Class F-1, G-1, or G-II

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos and bacteriological parameters) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards *Groundwater recharge by injection of Class G-1 and F-1 groundwaters and Class G-II groundwaters containing 3000 mg/l or less of TDS:* • Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided	as reclaimed water limits to be analyzed quarterly • pH - daily • Except for total coliforms and pH, 24-hour composite samples to be used for parameters listed as primary or secondary drinking water standards • Unregulated organic contaminants to be sampled annually for some types of projects • Monitoring for *Giardia* and *Cryptosporidium* required quarterly or one time during each two-year period depending on type of project • Parameters to be monitored and sampling	requirements • Minimum system size of 0.1 MGD • Staffing - 24 hrs/day, 7 days/wk for systems required to provide full treatment and disinfection - reduced staffing requirement to 6 hrs/day, 7 days/wk may be approved for systems not required to provide full treatment with diversion of reclaimed water to reuse system only during periods of operator presence and other provisions for increased reliability			parameters based on site specific conditions and groundwater quality	are provided	groundwaters and discharge to surface waters which are directly connected to Class F-1, G-I or G-II groundwaters • Public notification and public hearing requirements • Pilot testing is required for all projects that are required to provide full treatment and disinfection

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• 5 mg/l TSS (single sample) to be achieved prior to disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards • TOC - 3 mg/l (monthly average) - 5 mg/l (single sample) • Total organic halogen (TOX) - 0.2 mg/l (monthly average) - 0.3 mg/l (single sample) • Alternative TOC and TOX limitations may	frequency to be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity						

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	be approved if certain conditions are met *Groundwater recharge by injection of Class G-II groundwaters containing greater than 3000 mg/l of TDS:* • Same treatment and water quality requirements as above except TOC, TOX and secondary drinking water requirements do not apply • Limitations to be met before injection to groundwater							
Hawaii	• Determined on a case-by-case basis • Recycled water used for groundwater recharge by surface or subsurface application shall be at all	• Determined on a case-by-case basis	• Multiple or standby units required of sufficient capacity to enable effective operation with any one unit out of service • Alarm devices	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary		• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on		• Department of Health evaluation of proposed groundwater recharge projects and expansion of existing projects made on an

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	times of a quality that fully protects public health • Projects that are over an aquifer classified as nonpotable, where the design monthly (deep) percolation rate (DMPR) is greater than 20 percent of the maximum monthly application rate minus the DMPR, will be designated as a recharge project • Projects that are over an aquifer classified as potable, where the application rates exceed the consumptive evapotranspiration of the vegetative cover, will be designated as a		required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of chlorine residual • Standby power source required for treatment plant and distribution pump stations	• Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow • Emergency system storage not required where an alternate effluent disposal system has been approved		site size, site characteristics, location, method of discharge and other appropriate considerations • One well upgradient and two wells downgradient for project sites 500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address concerns of public health or		individual case basis where the use of reclaimed water involves a potential risk to public health • Evaluation based on all relevant aspects of each project including treatment provided, effluent quality and quantity, effluent or application spreading area operation, soil characteristics, hydrogeology, residence time, and distance to withdrawal • A public hearing or a public referendum is required for the DOH to review a request to augment a potable water supply by recharging the potable water

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	recharge project					environmental protection as related to variable characteristics of the subsurface or of the operations of the project		supply aquifer with recycled water
Massachusetts	• Secondary • Filtration (possibly) • Disinfection • pH 6 - 9 • BOD - less than 10 mg/l or 30 mg/l • Turbidity - less than 2 NTU or 5 NTU • Fecal coliform - median of no detectable colonies/100 ml over continuous, running 7 day sampling periods, not to exceed 14/100 ml or 200/100 ml • TSS - 5 mg/l or 10 mg/l • Total nitrogen - less than 10 mg/l	• pH - weekly or daily • BOD - weekly • Turbidity - continuous • Fecal coliform - daily or twice per week • Metals - quarterly • TSS - weekly or twice per week • Nitrogen - once or twice per week • MS-2 phage - quarterly • Total culturable viruses - quarterly • Variable testing requirements • UV intensity or chlorine residual - daily	• EPA Class I Reliability standards may be required • Two independent and separate sources of power • Unit redundancy • Additional storage	• Immediate, permitted discharge alternatives are required for emergency situations		*A groundwater monitoring plan is required and must accomplish the following goals:* • Evaluates upgradient (background) groundwater quality • Evaluates the performance of land use components that are considered part of the treatment process • Evaluates the overall impact of the project on local groundwater quality • Acts as an early warning	• No wastewater discharges will be permitted in the Zone I of any public water supply well defined as the area encompassing a maximum 400-foot radius around the wellhead (assuming a greater than 100,000 gpd withdrawal rate) • Discharging to Zone IIs, defined as the entire extent of the aquifer deposits which could fall within and upgradient from the production	• Refers to discharges into aquifer recharge areas as defined by Zone II boundaries of community water systems and groundwater discharges that will recharge reservoirs or tributaries to reservoirs • New treatment plants located in approved Zone IIs with less than a two year groundwater travel time to the public water supply well must treat to the more

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• Class I Groundwater Permit Standards (SDWA Drinking Water Standards)					system between the discharge and sensitive receptors	well's capture zone based on the predicted drawdown after 180-day drought conditions at the approved pumping rate, will be permitted in circumstances where it is necessary to replenish streamflow, enhance the productivity and capacity of an aquifer and/or improve upon or mitigate poor existing environmental conditions	rigorous of the two standards described • Existing treatment plants that can demonstrate four or five feet of separation and where the well has not shown any evidence of water quality degradation may maintain the lesser standard
Washington	*Nonpotable aquifer recharge:* • Class A - oxidized, coagulated, filtered and disinfected • Total coliform - 2.2/100 ml (7-day median) - 23/100 ml (single sample)	• Point of compliance is the point of direct recharge of reclaimed water into the underground • BOD – 24-hour composite samples collected at	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term,	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for		• Will be required and based on reclaimed water quality and quantity, site-specific soil and hydrogeologic characteristics and other considerations	• Reclaimed water withdrawn for nonpotable purposes can be withdrawn at any distance from the point of direct recharge • The minimum horizontal	• Defined as direct recharge to nonpotable or potable groundwater aquifers • Reclaimed water withdrawn for nonpotable purposes can be withdrawn

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• 5 mg/l BOD and TSS (7-day mean) • Turbidity - 2 NTU (monthly mean) - 5 NTU (single sample) • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes based on peak hourly flow • A chlorine residual of at least 0.5 mg/l to be maintained in the reclaimed water during conveyance to the point of recharge *Potable aquifer recharge:* • Oxidized, coagulated, filtered, reverse-osmosis treated and disinfected • Total coliform - 1/100 ml (7-day median) - 5/100 ml (single sample)	least daily • TSS – 24-hour composite samples collected at least daily • Total coliform - grab samples collected at least daily and at a time when wastewater characteristics are most demanding on the treatment facilities and disinfection procedures • Continuous on-line monitoring of turbidity and chlorine residual *Additional monitoring requirements for potable aquifer recharge:* • TOC - 24-hour composite samples collected at least daily • Primary contaminants (except total	20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the system is operating	duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that portion of the average daily flow for which no alternative reuse or disposal system is permitted		*Nonpotable aquifer recharge:* • Monitoring wells shall be established on a case-by-case basis • Constituents to be sampled shall be determined on a case-by-case basis • Samples from monitoring wells and their sampling frequency shall be determined on a case-by-case basis *Potable aquifer recharge:* • Monitoring wells, at a minimum, shall be located at points 500 feet and 1,000 feet (plus or minus 10%) along the groundwater flow path from the point of recharge to the nearest point of withdrawal of groundwater	separation distance between the point of direct recharge and withdrawal as a source of drinking water supply shall be 2,000 feet	at any time after direct recharge • Reclaimed water shall be retained underground for a minimum of 12 months prior to being withdrawn as a source of drinking water supply • Project evaluation based on all relevant aspects of each project, including treatment and treatment reliability provided, reclaimed water quality and quantity, use or potential use of groundwater, operation and management of the recharge facilities, soil characteristics, hydrogeology, residence time

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• 5 mg/l BOD and TSS (7 day mean) • Turbidity - 0.1 NTU (monthly mean) - 0.5 NTU (maximum) • Total nitrogen - 10 mg/l as N (annual mean) • TOC - 1.0 mg/l (monthly mean) • Water quality criteria for primary contaminants (except nitrate), secondary contaminants, radionuclides and carcinogens listed in Table 1 in chapter 173-200 WAC and any other maximum contaminant levels pursuant to chapter 246-290 WAC must be met • Minimum chlorine residual of 1 mg/l after a	coliform organisms), secondary contaminants, radionuclides, and carcinogens - 24-hour composite samples collected at least quarterly • Total nitrogen - grab or 24-hour composite samples collected at least weekly				used as a source of drinking water supply • Groundwater shall be sampled for TOC and primary contaminants, secondary contaminants, radionuclides, and carcinogens listed in Table 1 in chapter 173-200 WAC • Samples from monitoring wells shall be collected at least quarterly		of the reclaimed water in the underground prior to withdrawal and distance from the recharge area to nearest point of withdrawal • A pilot plant study shall be performed prior to implementation of direct recharge into a potable groundwater aquifer

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Table A-9. Groundwater Recharge

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	contact time of 30 minutes based on peak hourly flow • A chlorine residual of at least 0.5 mg/l to be maintained in the reclaimed water during conveyance to the point of recharge							

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
California	• Determined on a case-by-case basis • Based on all relevant aspects of each project, including the following factors: treatment provided; effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time and distance to withdrawal	•	•		•	•	•	
Florida	*Discharge to Class I surface waters and to water contiguous to or tributary to Class I waters (less than 4 hours travel time):* • Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 5 mg/l TSS	• Continuous on-line monitoring for turbidity before application of the disinfectant • Continuous monitoring for chlorine residual or for residual concentrations of other disinfectants • Treatment facilities designed to	• Class I reliability - requires multiple or backup treatment units and a secondary power source • For treatment facilities required to provide full treatment and disinfection - minimum reject storage	• System storage not required • If system storage is provided, at a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or	• Reasonable assurances must be provided that the hydraulic loading rates used in the design must enable the system to comply with the requirements while meeting applicable surface water and	• Required • 1 upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • 1 well at the edge of the zone of discharge down-gradient of the site	• Outfalls for surface water discharges not to be located within 500 feet of existing or approved potable water intakes within Class I surface waters • Zones of discharge not to extend closer than 500 feet to a potable water	• Involves the planned use of reclaimed water to augment Class F-1, G-1, or G-II groundwaters identified for potable water use and defined as groundwater recharge in regulations • Types of groundwater

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	(single sample) to be achieved prior to disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards • TOC - 3 mg/l (monthly average) - 5 mg/l (single sample) *Use of rapid-rate land application systems for projects considered reuse for groundwater recharge under 62-610.525:* • Secondary treatment with filtration and	meet the full treatment and disinfection requirements to sample for TOC and total organic halogen daily, 7 days per week • Total coliforms and TSS analyzed daily if treatment facility is required to meet bacteriological requirements of the drinking water standards • Parameters listed as primary drinking water standards that are imposed as reclaimed water limits to be analyzed monthly • Parameters listed as secondary drinking water standards that are imposed	capacity equal to 3 day's flow at the average daily permitted flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • If full treatment and disinfection is not required, the capacity requirement for reject storage shall be reduced to one day's flow • Reject storage will not be required if another permitted reuse system or effluent disposal system is capable of discharging the reject water in accordance with requirements	disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation	groundwater quality standards • A groundwater mounding analysis is to be included in the engineering report for projects involving discharges to groundwater and should provide reasonable assurances that the proposed project will function as intended and will not result in excessive mounding of groundwaters, increases in surface water elevations, property damage or interference with reasonable use of property within the affected area	(compliance well) • 1 well downgradient from the site and within the zone of discharge (intermediate well) • 1 well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for additional	supply well • 1,000 foot setback distance from injection well used for salinity barrier control to potable water supply wells *Injection facilities:* • 500 feet to potable water supply wells that are existing or have been approved; Class I surface waters; or Class II surface waters • Setback distance to Class I and Class II surface waters reduced to 100 feet if high-level disinfection is provided • 100 feet to buildings not part of the treatment facility, utilities	recharge systems include injection of reclaimed water into Class F-1, G-1, or G-II groundwaters, specific rapid-rate land application systems, use of reclaimed water to create barriers to the landward or upward migration of salt water within Class F-1, G-1, or G-II groundwaters and discharge to surface waters which are directly connected to Class F-1, G-I or G-II groundwaters • Indirect potable reuse Involves the planned use of reclaimed water to

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	high-level disinfection • Chemical feed facilities to be provided • 5 mg/l TSS (single sample) to be achieved prior to disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos and bacteriological parameters) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards *Groundwater recharge by injection of Class G-1 and F-1 groundwaters and Class G-II groundwaters containing 3000 mg/l or less of*	as reclaimed water limits to be analyzed quarterly • pH - daily • Except for total coliforms and pH, 24-hour composite samples to be used for parameters listed as primary or secondary drinking water standards • Unregulated organic contaminants to be sampled annually for some types of projects • Monitoring for *Giardia* and *Cryptosporidium* required quarterly or one time during each 2-year period depending on type of project • Parameters to be monitored and sampling frequency to	• Minimum system size of 0.1 mgd • Staffing - 24 hrs/day, 7 days/wk for systems required to provide full treatment and disinfection - reduced staffing requirement to 6 hrs/day, 7 days/wk may be approved for systems not required to provide full treatment with diversion of reclaimed water to reuse system only during periods of operator presence and other provisions for increased reliability			parameters based on site-specific conditions and groundwater quality	system or municipal operations • 100 feet to site property line • Some setback distances may be reduced if certain treatment requirements are met and assurances are provided	augment surface water resources which are used or will be used for public water supplies and includes discharges to Class I surface waters and discharges to other surface waters which are directly or indirectly connected to Class I surface waters • Public notification and public hearing requirements in place for projects involving surface water discharges and underground injection • Pilot testing is required for all projects that are required to provide full treatment and disinfection

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	TDS: • Same treatment and water quality requirements as discharge to Class I surface waters except additional requirement for total organic halogen must be met • Total organic halogen (TOX) - 0.2 mg/l (monthly average) - 0.3 mg/l (single sample • Alternative TOC and TOX limitations may be approved if certain conditions are met *Groundwater recharge by injection of Class G-II groundwaters containing greater than 3000 mg/l of TDS:* • Same treatment and water quality requirements	be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity						

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	as discharge to Class I surface waters except TOC and secondary drinking water requirements do not apply • Limitations to be met before injection to groundwater or discharge to surface waters							
Hawaii	• Determined on a case-by-case basis • Reclaimed water used for groundwater recharge by surface or subsurface application shall be at all times of a quality that fully protects public health • Projects that are over an aquifer classified as potable, where the application rates exceed the consumptive	• Determined on a case-by-case basis	• Multiple or standby units required of sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow		• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on site size, site characteristics, location, method of discharge, and other appropriate considerations • One well upgradient and two wells downgradient for project sites		• Department of Health evaluation of proposed groundwater recharge projects and expansion of existing projects made on an individual case basis where the use of recycled water involves a potential risk to public health • Evaluation based on all relevant aspects of each project including

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	evapotranspiration of the vegetative cover, will be designated as a recharge project		chlorine residual • Standby power source required for treatment plant and distribution pump stations	• Emergency system storage not required where an alternate effluent disposal system has been approved		500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address concerns of public health or environmental protection as related to variable characteristics of the subsurface or of the operations of the project		treatment provided, effluent quality and quantity, effluent or application spreading area operation, soil characteristics, hydrogeology, residence time, and distance to withdrawal • A public hearing or a public referendum is required for the DOH to review a request to augment a potable water supply by recharging the potable water supply aquifer with recycled water
Massachusetts	• Secondary • Filtration (possibly)	• pH - weekly or daily • BOD - weekly	• EPA Class I Reliability standards may	• Immediate, permitted discharge		*A groundwater monitoring plan is required and*	• No wastewater discharges will be permitted in	• Refers to discharges into aquifer

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• Disinfection • pH 6 - 9 • BOD - less than 10 mg/l or 30 mg/l • Turbidity - less than 2 NTU or 5 NTU • Fecal coliform - median of no detectable colonies/100 ml over continuous, running 7-day sampling periods, not to exceed 14/100 ml or 200/100 ml • TSS - 5 mg/l or 10 mg/l • Total nitrogen - less than 10 mg/l • Class I Groundwater Permit Standards (SDWA Drinking Water Standards)	• Turbidity - continuous • Fecal coliform - daily or twice per week • Metals - quarterly • TSS - weekly or twice per week • Nitrogen - once or twice per week • MS-2 phage - quarterly • Total culturable viruses - quarterly • Variable testing requirements • UV intensity or chlorine residual - daily	be required • Two independent and separate sources of power • Unit redundancy • Additional storage	alternatives are required for emergency situations		*must accomplish the following goals:* • Evaluates upgradient (background) groundwater quality • Evaluates the performance of land use components that are considered part of the treatment process • Evaluates the overall impact of the project on local groundwater quality • Acts as an early warning system between the discharge and sensitive receptors	the Zone I of any public water supply well defined as the area encompassing a maximum 400-foot radius around the wellhead (assuming a greater than 100,000 gpd withdrawal rate) • Discharging to Zone IIs, defined as the entire extent of the aquifer deposits which could fall within and upgradient from the production well's capture zone based on the predicted drawdown after 180-day drought conditions at the approved pumping rate, will be permitted in circumstances where it is	recharge areas as defined by Zone II boundaries of community water systems and groundwater discharges that will recharge reservoirs or tributaries to reservoirs • New treatment plants located in approved Zone IIs with less than a 2 year groundwater travel time to the public water supply well must treat to the more rigorous of the two standards described • Existing treatment plants that can demonstrate 4 or 5 feet of separation and where the well has not shown any evidence of water quality

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
							necessary to replenish streamflow, enhance the productivity and capacity of an aquifer, and/or improve upon or mitigate poor existing environmental conditions	degradation may maintain the lesser standard
Washington	• Oxidized, coagulated, filtered, reverse-osmosis treated and disinfected • Total coliform - 1/100 ml (7-day median) - 5/100 ml (single sample) • 5 mg/l BOD and TSS (7-day mean) • Turbidity - 0.1 NTU (monthly mean) - 0.5 NTU (maximum) • Total nitrogen - 10 mg/l as N (annual mean) • TOC - 1.0 mg/l	• Point of compliance is the point of direct recharge of reclaimed water into the underground • BOD – 24-hour composite samples collected at least daily • TSS - 24 hour composite samples collected at least daily • Total coliform - grab samples collected at least daily and at a time when wastewater	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the system is operating	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that		• Will be required and based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics and other considerations • For direct recharge into potable groundwater aquifers, monitoring wells, at a minimum, shall be located at points 500 feet and 1,000 feet (plus or minus	• The minimum horizontal separation distance between the point of direct recharge and withdrawal as a source of drinking water supply shall be 2,000 feet	• Defined as direct recharge to potable groundwater aquifers • Reclaimed water shall be retained underground for a minimum of 12 months prior to being withdrawn as a source of drinking water supply • Project evaluation based on all relevant aspects of each project, including treatment and

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	(monthly mean) • Water quality criteria for primary contaminants (except nitrate), secondary contaminants, radionuclides and carcinogens listed in Table 1 in Chapter 173-200 WAC and any other maximum contaminant levels pursuant to Chapter 246-290 WAC must be met • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes based on peak hourly flow • A chlorine residual of at least 0.5 mg/l to be maintained in the reclaimed water during conveyance to the point of recharge	characteristics are most demanding on the treatment facilities and disinfection procedures • Continuous on-line monitoring of turbidity and chlorine residual • TOC - 24-hour composite samples collected at least daily • Primary contaminants (except total coliform organisms), secondary contaminants, radionuclides, and carcinogens - 24-hour composite samples collected at least quarterly • Total nitrogen - grab or 24-hour composite samples		portion of the average daily flow for which no alternative reuse or disposal system is permitted		10 percent) along the groundwater flow path from the point of recharge to the nearest point of withdrawal of groundwater used as a source of drinking water supply • Groundwater shall be sampled for TOC and primary contaminants, secondary contaminants, radionuclides, and carcinogens listed in Table 1 in Chapter 173-200 WAC • Samples from monitoring wells shall be collected at least quarterly		treatment reliability provided, reclaimed water quality and quantity, use or potential use of groundwater, operation and management of the recharge facilities, soil characteristics, hydrogeology, residence time of the reclaimed water in the underground prior to withdrawal and distance from the recharge area to nearest point of withdrawal • A pilot plant study shall be performed prior to implementation of direct recharge into a potable groundwater aquifer

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
		collected at least weekly						

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Appendix B

State Websites

Appendix B. State Website Internet Addresses

State	Type	Agency	Rules	Website
Alabama	Guidelines	Department of Environmental Management	Guidelines and Minimum Requirements for Municipal, Semi-Public and Private Land Treatment Facilities	http://www.adem.state.al.us/ http://209.192.62.106/ Land treatment guidelines not found on website
Alaska	Regulations	Department of Environmental Conservation	Alaska Administrative Code, Title 18 - Environmental Conservation, Chapter 72, Article 2, Section 275 - Disposal Systems	http://www.state.ak.us/local/akpages/ENV.CONSERV/home.htm http://www.state.ak.us/local/akpages/ENV.CONSERV/title18/aac72ndx.htm
Arizona	Regulations	Department of Environmental Quality	Arizona Administrative Code, Title 18 - Environmental Quality, Chapter 11, Article 3 - Reclaimed Water Quality Standards and Chapter 9, Article 7 - Direct Reuse of Reclaimed Water	http://www.sos.state.az.us/ http://www.sos.state.az.us/public_services/Table_of_Contents.htm
Arkansas	Guidelines	Department of Environmental Quality	Arkansas Land Application Guidelines for Domestic Wastewater	http://www.adeq.state.ar.us/default.htm http://www.adeq.state.ar.us/water/branch_permits/default.htm Land application guidelines not found on website
California	Regulations	Department of Health Services	California Department of Health Services Regulations and Guideance for Recycled Water (The Purple Book) California Code of Regulations, Title 17 and 22	http://www.dhs.cahwnet.gov http://www.dhs.ca.gov/ps/ddwem/publications/waterrecycling/waterrecyclingindex.htm http://ccr.oal.ca.gov/
Colorado	Regulations	Department of Public Health and Environment	Water Quality Control Commission Regulation 84-Reclaimed Domestic Wastewater Control Regulation	http://www.cdphe.state.co.us/cdphehom.asp http://www.cdphe.state.co.us/op/regs/waterregs/100284.pdf
Connecticut	Neither	Department of Environmental Protection	---	http://dep.state.ct.us/
Delaware	Regulations	Department of Natural Resources and Environmental Control	Guidance and Regulations Governing the Land Treatment of Wastes	http://www.dnrec.state.de.us/dnrec2000/ http://www.dnrec.state.de.us/water2000/Sections/GroundWat/GWDSRegulations.htm
Florida	Regulations	Department of Environmental Protection	Reuse of Reclaimed Water and Land Application Florida Administrative Code - Chapter 62-610	http://www.dep.state.fl.us/ http://www.dep.state.fl.us/water/reuse/index.htm http://fac.dos.state.fl.us/
Georgia	Guidelines	Department of Natural Resources	Environmental Protection Division Guidelines for Water Reclamation and Urban Water Reuse	http://www.dnr.state.ga.us/dnr/environ/ http://www.ganet.org/dnr/environ/techguide_files/wpb/reuse.pdf
Hawaii	Guidelines	Department of Health	Guidelines for the Treatment and Use of Recycled Water	http://www.state.hi.us/doh/ http://www.state.hi.us/doh/eh/wwb/reuse-final.pdf
Idaho	Regulations	Department of Environmental Quality	58.01.17 Wastewater Land Application Permit Rules	http://www2.state.id.us/adm/index.htm http://www2.state.id.us/adm/adminrules/rules/idapa58/58index.htm
Illinois	Regulations	Environmental Protection Agency	Illinois Administrative Code, Title 35, Subtitle C, Part 372, Illinois Design Standards for Slow Rate Land Application of Treated Wastewater	http://www.ipcb.state.il.us/ http://www.ipcb.state.il.us/SLR/IPCBandIEPAEnvironmentalRegulations-Title35.asp
Indiana	Regulations	Department of Environmental Management	Indiana Administrative Code, Title 327, Article 6.1-Land Application of Biosolid, Industrial Waste Product, and Pollutant-Bearing Water	http://www.in.gov/idem/ http://www.in.gov/legislative/iac/title327.html
Iowa	Regulations	Department of Natural Resources	Environmental Protection Division Iowa Wastewater Design Standards, Chapter 21 - Land Application of Wastewater	http://www.state.ia.us/epd/ http://www.state.ia.us/epd/wastewtr/design.htm
Kansas	Guidelines	Department of Health and Environment	KDHE Administrative Rules and Regulations, 28-16. Water Pollution Control	http://www.kdhe.state.ks.us/ http://www.kdhe.state.ks.us/regs/
Kentucky	Neither	---	---	http://kentucky.gov/Default.html
Louisiana	Neither	---	---	http://www.state.la.us/
Maine	Neither	---	---	http://www.state.me.us/

Appendix B. State Website Internet Addresses Continued

State	Type	Agency	Rules	Website
Maryland	Guidelines	Department of the Environment	Guidelines for Land Treatment of Municipal Wastewaters Title 26 Department of the Environment	http://www.mde.state.md.us/index.asp http://www.dsd.state.md.us/comar/subtitle_chapters/26_Chapters.htm
Massachusetts	Guidelines	Massachusetts Department of Environmental Protection	Interim Guidelines on Reclaimed Water (Revised)	http://www.state.ma.us/dep/dephome.htm http://www.state.ma.us/dep/brp/wwm/t5regs.htm
Michigan	Regulations	Department of Environmental Quality	Part 22 Rules of Part 31Groundwater Quality Rules Part 22 Guidesheet II Irrigation Management Plan Rule 2215 Various Aboveground Disposal Systems	http://www.michigan.gov/deq http://www.michigan.gov/deq/0,1607,7-135-3313_3682-14902--,00.html http://www.michigan.gov/deq/0,1607,7-135-3312_4117-9782--,00.html http://www.deq.state.mi.us/documents/deq-wmd-gwp-Rule2215VariousAboveGroundDisposalSystems-
Minnesota	Neither	---	---	http://www.state.mn.us/cgi-bin/portal/mn/jsp/home.do?agency=NorthStar
Mississippi	Neither	---	---	http://www.mississippi.gov/
Missouri	Regulations	Department of Natural Resources	Code of State Regulations, Title 10, Division 20, Chapter 8 - Design Guides	http://www.sos.mo.gov/ http://www.sos.mo.gov/adrules/csr/current/10csr/10csr.asp
Montana	Guidelines	Department of Environmental Quality	Design Standards for Wastewater Facilities, Appendix B - Standards for the Spray Irrigation of Wastewater	http://www.deq.state.mt.us/ http://www.deq.state.mt.us/wqinfo/Circulars/DEQ2.PDF
Nebraska	Regulations	Department of Environmental Quality	Title 119 Chapter 9 Disposal of Sewage Sludge and Land Application of Effluent - Regulations refer to the use of Guidelines for Treated Wastewater Irrigation Systems, February 1986	http://www.deq.state.ne.us/
Nevada	Regulations	Department of Conservation and Natural Resources	Divison of Environmental Protection Nevada Administrative Code 445A.275 - Use of Treated Effluent for Irrigation General Design Criteria for Reclaimed Water Irrigation Use	http://ndep.nv.gov/ http://ndep.nv.gov/nac/445a-226.pdf http://ndep.nv.gov/bwpc/wts1a.pdf
New Hampshire	Neither	---	---	http://www.state.nh.us/
New Jersey	Guidelines	Department of Environmental Protection-Division of Water Quality	Technical Manual for Reclaimed Water for Beneficial Reuse	http://www.state.nj.us/dep/dwq/techman.htm
New Mexico	Guidelines	Environment Department	Use of Domestic Wastewater Effluent for Irrigation	http://www.nmenv.state.nm.us/ Guidelines not found on website
New York	Guidelines	Department of Environmental Conservation	State Guidelines for the Use of Land Treatment of Wastewater	http://www.dec.state.ny.us/ Guidelines not found on website
North Carolina	Regulations	Department of Environment and Natural Resources	Administrative Rules, Title 15A, Chapter 02, Subchapter H, .0200 - Waste not Discharged to Surface Waters	http://www.oah.state.nc.us/rules/ http://ncrules.state.nc.us/ncadministrativ_/title15aenviron_/chapter02enviro_/default.htm
North Dakota	Guidelines	Department of Health	Division of Water Quality Criteria for Irrigation with Treated Wastewater Recommended Criteria for Land Disposal of Effluent	http://www.health.state.nd.us/wq/
Ohio	Guidelines	Environmental Protection Agency	The Ohio State University Extension Bulletin 860 Reuse of Reclaimed Wastewater through Irrigation	http://www.epa.state.oh.us/ http://ohioline.osu.edu/b860/
Oklahoma	Regulations	Department of Environmental Quality	Title 252 Chapter 621 and 656	http://www.deq.state.ok.us/mainlinks/deqrules.htm

Appendix B. State Website Internet Addresses Continued

State	Type	Agency	Rules	Website
Oregon	Regulations	Department of Environmental Quality	Oregon Administrative Rules Use of Reclaimed Water from Sewage Treatment Plants - Division 55 340-055 Treatment and Monitoring Requirements for Use of Reclaimed Water	http://www.deq.state.or.us/wq/wqrules/wqrules.htm
Pennsylvania	Guidelines	Department of Environmental Protection	Bureau of Water Quality Protection Manual for Land Application of Treated Sewage and Industrial Wastewater	http://www.dep.state.pa.us/dep/deputate/watermgt/Wqp/WQP_WM/WM_Sewage.htm
Rhode Island	Neither	---	---	http://www.state.ri.us/
South Carolina	Regulations	Department of Health and Environmental Control	Administrative Code 61 Section 9.505 Land Application Permits and State Permits	http://www.lpitr.state.sc.us/coderegs/chap61/61-9.htm
South Dakota	Guidelines	Department of Environment and Natural Resources	Chapter XII Recommended Design Criteria for Disposal of Effluent by Irrigation Chapter XIII Recommended Design Criteria for Groundwater Monitoring Wells Chapter XVI Recommended Design Criteria for Artificial Wetland Systems	http://www.state.sd.us/denr/DES/P&S/designcriteria/designT.html
Tennessee	Regulations	Department of Environment and Conservation	Chapter 16 of Design Criteria for Sewage Works	http://www.state.tn.us/environment/
Texas	Regulations	Natural Resource Conservation Commission	Texas Administrative Code, Title 30 Environmental Quality, Part 1, Chapter 210 Use of Reclaimed Water	http://info.sos.state.tx.us/pub/plsql/readtac$ext.viewtac
Utah	Regulations	Department of Environmental Quality Division of Water Quality	Utah Administrative Code, Environmental Quality, R-317-1-4	http://www.rules.utah.gov/publicat/code.htm
Vermont	Regulations	Agency of Natural Resources Department of Environmental Conservation	Indirect Discharge Rules (for systems >6500 gpd) Wastewater Disposal Systems and Potable Water Supplies (for systems <6500 gpd)	http://www.anr.state.vt.us/ http://www.anr.state.vt.us/dec/ww/indirect.htm#IDRs http://www.anr.state.vt.us/dec/ww/rules/os/Final081602/Subchap5-6-081602.pdf
Virginia	Neither	Department of Environmental Quality		http://www.virginia.gov/cmsportal/
Washington	Guidelines	Department of Health State	Department of Ecology Water Reclamation and Reuse Standards	http://www.ecy.wa.gov/ecyhome.html http://www.ecy.wa.gov/biblio/97023.html
West Virginia	Regulations	Department of Health	Title 64 Series 47 Chapter 16-1 Sewage Treatment and Collection System Design Standards	http://www.wvsos.com/csr/verify.asp?TitleSeries=64-47
Wisconsin	Regulations	Department of Natural Resources	Natural Resources, Chapter NR 206 Land Disposal of Municipal and Domestic Wastewaters	http://www.dnr.state.wi.us/ www.legis.state.wi.us/rsb/code
Wyoming	Regulations	Department of Environmental Quality	Wyoming Water Quality Regulations Chapter 21-Reuse of Treated Wastewater	http://soswy.state.wy.us/ http://soswy.state.wy.us/RULES/2804.pdf

Appendix C

Abbreviations and Acronyms

Acronyms

AID	U.S. Agency for International Development
ANSI	American National Standards Institute
AWT	advanced wastewater treatment
AWWA	American Water Works Association
BNR	biological nutrient removal
BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CFU	colony forming units
COD	chemical oxygen demand
COE	U.S. Army Corps of Engineers
CWA	Clean Water Act
DO	dissolved oxygen
EC	electrical conductivity
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ESA	external support agency
ET	evapotranspiration
FC	fecal coliform
FmHA	Farmers Home Administration
GAC	granular activated carbon
GC/MS	gas chromatography/mass spectroscopy
HPLC	high pressure liquid chromatography
IAWPRC	International Association on Water Pollution Research and Control
ICP	inductively coupled plasmography
I/I	infiltration/inflow
IOC	inorganic chemicals
IRCWD	International Reference Centre for Waste Disposal
IRWD	Irvine Ranch Water District
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDL	method detection limit
MPN	most probable number
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NRC	National Research Council
NTU	nephelometric turbidity units
O3	ozone
O&M	operations and maintenance
OM&R	operations, maintenance and replacement
OWRT	Office of Water Research and Technology
PAC	powder activated carbon
PCB	polychlorinated biphenyls
POTW	publicly owned treatment works
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RAS	return activated sludge
RBC	rotating biological contactor
RO	reverse osmosis
SAR	sodium adsorption ratio
SAT	soil aquifer treatment
SBA	Small Business Administration
SDWA	Safe Drinking Water Act
SOC	synthetic organic chemical
SRF	State Revolving Fund
SS	suspended solids
TCE	trichloroethylene
TDS	total dissolved solids
THM	trihalomethane
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TOH	total organic hydrocarbons
TOX	total organic halides
TP	total phosphorus
TPH	total petroleum hydrocarbon
TSS	total suspended solids
UN	United Nations
USDA	U.S. Department of Agriculture
UV	ultraviolet
VOC	volatile organic chemicals
WAS	waste activated sludge
WASH	Water and Sanitation for Health
WHO	World Health Organization
WPCF	Water Pollution Control Federation
WRF	water reclamation facility
WWTF	wastewater treatment facility

Abbreviations for Units of Measure

Acre	ac
Acre-foot	AF
British thermal unit	Btu
cubic feet per second	cfs
cubic meter	m^3
cubic meters per day	m^3/d
cubic meters per second	m^3/s
Curie	Ci
cycles per second	cps
degrees Celsius	^{o}C
degrees Fahrenheit	^{o}F
feet (foot)	ft
feet per year	ft/yr
Gallon	g
gallons per day	gpd
gallons per minute	gpm
hectare	ha
horsepower	hp
hour	hr
Inch	in
kilogram	kg
kilometer	km
kiloPascal	kPa
kilowatt	kW
kilowatt hour	kWh
Liter	l
liters per capita per day	lcd

liters per second	l/s
meter	m
meters per second	m/s
microgram	µg
micrograms per liter	µg/l
micrometer	µm
mile	mi
mile per hour	mph
milligram	mg
milligrams per liter	mg/l
millilter	ml
millimeter	mm
million gallons per day	mgd
milliquivalent per liter	meq/l
minute	min
megawatt	mW
million acre feet per year	MAFY
pascal	Pa
plaque forming unit	pfu
pound	lb
pounds per square inch	psi
roentgen	R
second	S
square foot	ft^2
square inch	in^2
square meter	m^2
year	yr

Appendix D

Inventory of Reclaimed Water Projects

Appendix D: Inventory of Water Reuse Projects

Projects Sponsored by the Water Environment Research Foundation (WERF)

Project Number	Project Title
01-CTS-6	Membrane Treatment of Secondary Effluent for Subsequent Use*
D13000	Membrane Bioreactors: Feasibility and Use in Water Reclamation
92-HHE-1CO	The Use of Reclaimed Water and Sludge in Food Crop Production (Cooperative Effort w/ NRC)
01-HHE-4	Workshop: On-line Toxicologic Methods for Evaluating Potential Chemical Risk Associated with Potable Reuse (Workshop)
01-HHE-4a	Online Methods for Evaluating the Safety of Reclaimed Water*
01-HHE-20T	Removal of Endocrine Disrupting Compounds in Water Reclamation Systems*
01-HHE-21T	Innovative DNA Array Technology for Detection of Pharmaceutics in Reclaimed Water*
97-IRM-6	Nonpotable Water Reuse Management Practices
00-PUM-1	Water Reuse: Understanding Public Participation and Participation
00-PUM-2T	Reduction of Pathogens, Indicator Bacteria, and Alternative Indicators by Wastewater Treatment and Reclamation Processes*
00-PUM-3	Evaluation of Microbial Risk Assessment Techniques and Applications in Water Reclamation*
94-PUM-1CO	Soil Treatability Pilot Studies to Design and Model Soil Aquifer Treatment Systems
99-PUM-4	Impact of Storage on Nonpotable Reclaimed Water: Seasonal and Long Term
92-WRE-1	Water Reuse Assessment

Appendix D: Inventory of Water Reuse Projects Continued	
Projects Sponsored by the American Water Works Association Research Foundation (AWWARF)	
Project Number	**Project Title**
371	Augmenting Potable Water Supplies With Reclaimed Water
487	Investigation of Soil-Aquifer Treatment for Sustainable Water Reuse
2568	Membrane Treatment of Waste Filter Washwater for Direct Reuse
2919	Understanding Public Concerns and Developing Tools to Assist Local Officials in Successful Potable Reuse Projects
2968	Protocol for Developing Water Reuse Criteria With Reference to Drinking Water Supplies
Projects Sponsored by the National Water Research Institute (NWRI)	
WR-699-531-92	A Comparative Study of UV and Chlorine Disinfection for Wastewater Reclamation
HRA-699-517-94	Microbial Risk Assessment for Reclaimed Water
Projects Sponsored by the WateReuse Foundation	
WRF-01-001	Develop Low Cost Analytical Method for Measuring NDMA
WRF-01-002	Removal and/or Destruction of NDMA in Wastewater Treatment Processes
WRF-01-004	Understanding Public Concerns of Indirect Potable Reuse Projects
WRF-01-005	Characterizing Salinity in Sewer Contributions in Sewer Collection and Reclaimed Water Distribution Systems (AwwaRF Project)
WRF-01-006	Characterizing Microbial Water Quality in Non-Potable Reclaimed Water Distribution Systems to Optimize End Uses (AwwaRF Project)
WRF-01-007	The Use of Bioassays and Chemical Measurements to Assess the Removal of Endocrine Disrupting Compounds in Water Reclamation Systems (WERF Project via JWRTF)
WRF-01-008	Evaluation and Testing of Bioassays for Pharmaceutics in Reclaimed Water (WERF Project via JWRTF)
WRF-02-001	Rejection of Wastewater-Derived Micropollutants in High-Pressure Membrane Applications Leading to Indirect Potable Reuse: Effects of Membrane and micropollutant Properties
WRF-02-002	Investigation of NDMA Fate and Transport
WRF-02-003	Filter Loading Evaluation for Water Reuse
WRF-02-004	National Database on Water Reuse Projects
WRF-02-005	Develop a National Salinity Management Clearinghouse and Five-year Research Program
WRF-02-006a	Zero Liquid Discharge for Water Utility Applications
WRF-02-006b	Beneficial and Non-Traditional Uses of Concentrate and Salts

Appendix D: Inventory of Water Reuse Projects Continued	
Projects Sponsored by the WateReuse Foundation Continued	
Project Number	**Project Title**
WRF-02-006c	Impacts of Membrane Process Residuals on Wastewater Treatment
WRF-02-006d	Benefits of Regional Solutions in Disposing of Concentrate
WRF-02-007	Comparative Study of Recycled Water Irrigation and Fairway Turf
WRF-02-008	Study of Reclaimed, Surface, and Ground-Water Quality
WRF-02-009	Study of Innovative Treatment on Reclaimed Water
WRF-02-011	A Protocol for Developing Water Reuse Criteria with Reference to Drinking Water Supplies
WRF-03-001	Pathogen Removal and Inactivation in Reclamation Plants - Study Design
WRF-03-005	Marketing Strategies for Non-Potable Recycled Water
WRF-03-006	Economic Analysis of Sustainable Water Use - Benefits and Cost
WRF-03-009	Reclaimed Water Aquifer Storage and Recovery: Potential Changes in Water Quality
WRF-03-010	Water Reuse Research Needs Workshop
WRF-03-011	Two-Day Research Needs Assessment Workshop on Integrating Human Reactions to Water Reuse
WRF-03-012	Salt Management Guide
WRF-03-013	Rejection of Contaminants of Concern by Nanofiltration and Ultra-low Pressure Reverse Osmosis Membranes for Treating Water of Impaired Quality (AWWARF)
WRF-03-014	Development of Indicators and Surrogates of Chemical Contaminants and Organic Removal in Wastewater and Water Reuse (Co-funding with WERF)

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United States
Environmental Protection
Agency

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EPA 625/R-04/108
August 2004
www.epa.gov