Water Reuse: Trends in the U.S.

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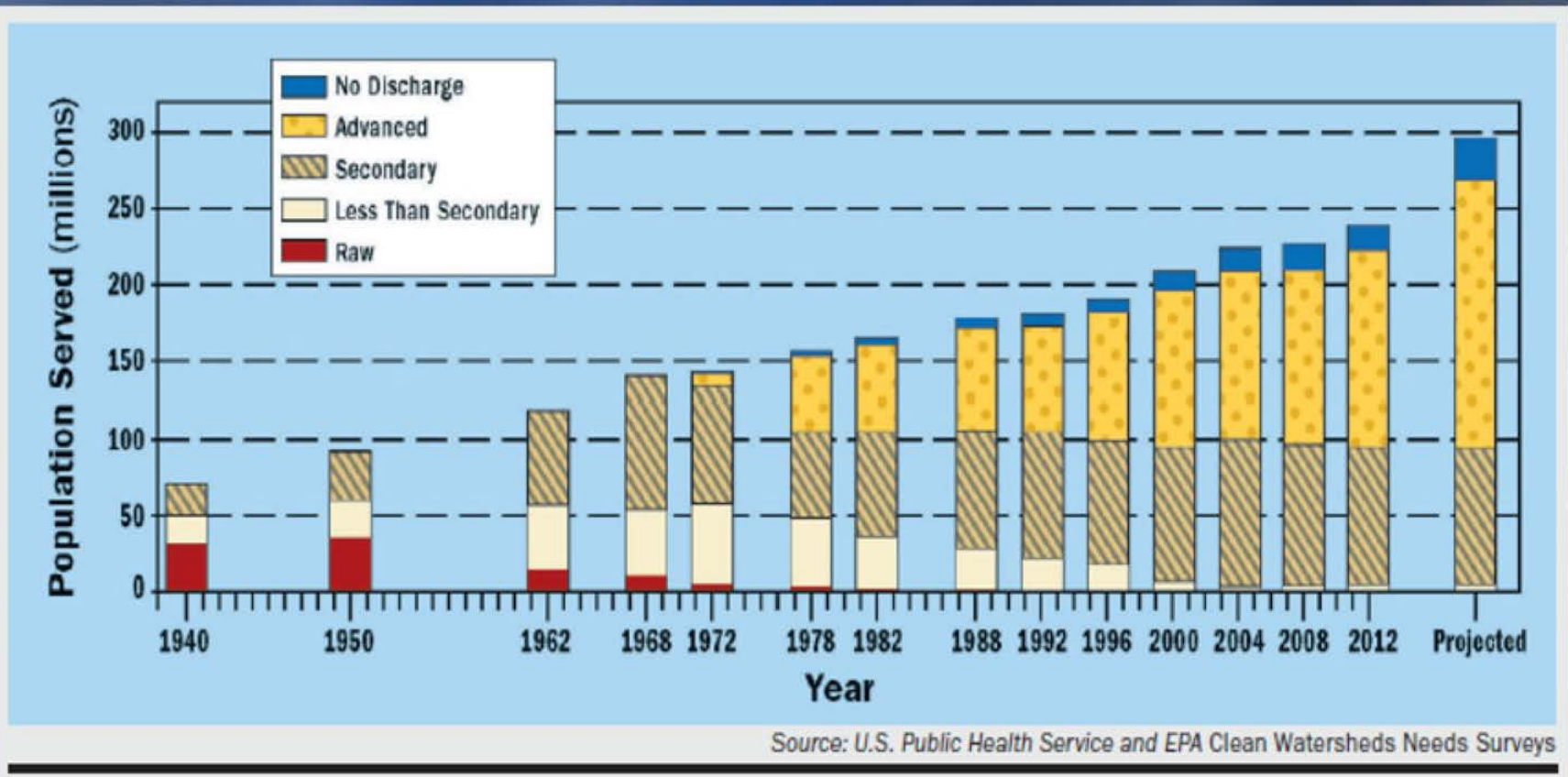


Source: *U.S. Public Health Service and EPA* Clean Watersheds Needs Surveys

Figure 5. Population Served by POTWs for Select Years between 1940 and 2012 and Projected (if All Needs Are Met) by Treatment Level.

Table 3. Improvements in Treatment Level of the Nation's POTWs

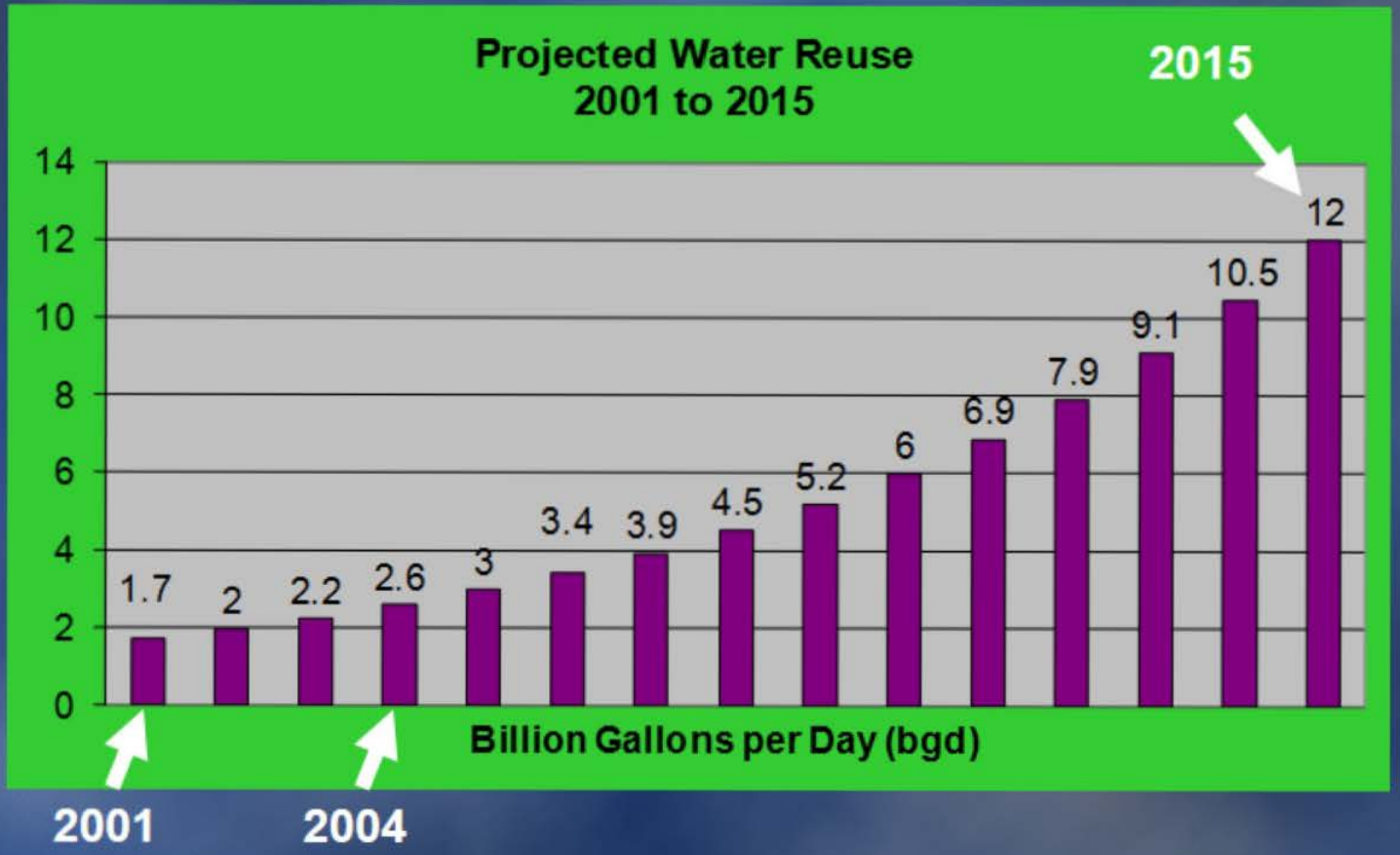
Level of treatment	Population served in millions (number of facilities)				Population change from 2008–2012	Projected population change from 2012–2032
	2004[a]	2008[a]	2012[a]	2032		
Less than Secondary[b]	3.3 (40)	3.8 (30)	4.1 (34)	4.5 (23)	8.2%	11%
Secondary	96.5 (9,221)	92.7 (7,302)	90.4 (7,374)	88.7 (6,670)	-2.4%	-2%
Greater than Secondary	108.5 (4,916)	113.0 (5,072)	127.7 (5,036)	174.9 (6,111)	13.0%	37%
No Discharge	14.6 (2,188)	16.9 (2,251)	16.0 (2,281)	26.7 (2,461)	-5.6%	67%
Partial Treatment	- (218)	- (115)	- (23)	- (15)	-	-
Total	**222.8 (16,583)**	**226.4 (14,770)**	**238.2 (14,748)**	**294.9 (15,280)**	**5.2%**	**24%**

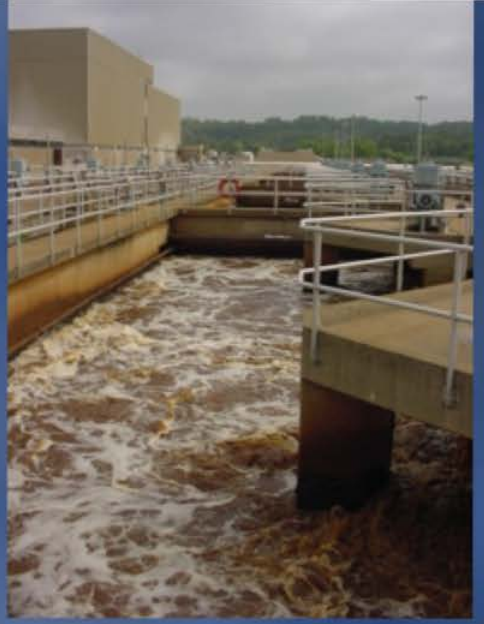
Note:
These facilities provide some treatment to wastewater and discharge their effluents to other facilities for further treatment and discharge. The population associated with these facilities is omitted from this table to avoid double counting.

[a] This table contains best available information from States and Territories that did not have the resources to complete the updating of the data or did not participate in the CWNS 2004 or 2008. In these circumstances, information for this table was taken from previous surveys.

[b] Includes facilities granted section 301(h) waivers from secondary treatment for discharges to marine waters. As of January 1, 2012, waivers for 36 facilities in the CWNS 2012 database had been granted or were pending.

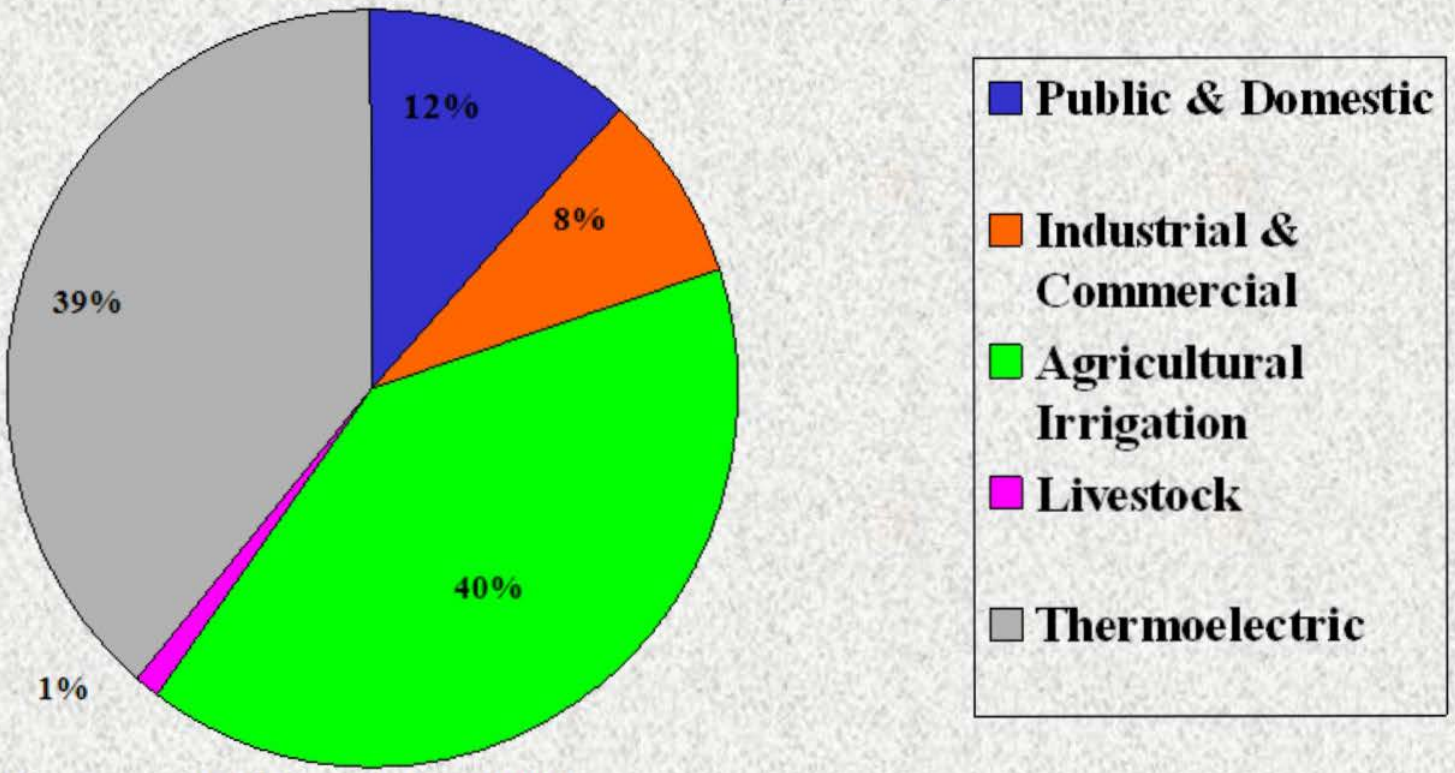
Projected Growth of Water Reuse in the U.S.





Water Supply, Water Usage (Ag, Domestic, Industrial)

U.S. Water Demands by Major Uses



Source: Solley, et al., 1988

USGS, 1995

Water Use by Sector

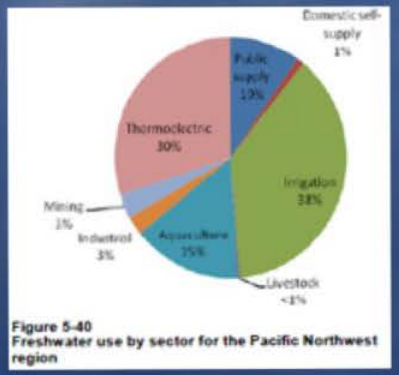


Figure 5-40
Freshwater use by sector for the Pacific Northwest region

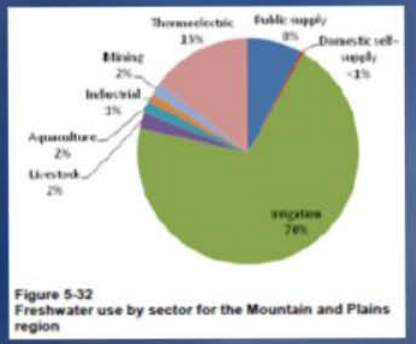


Figure 5-32
Freshwater use by sector for the Mountain and Plains region

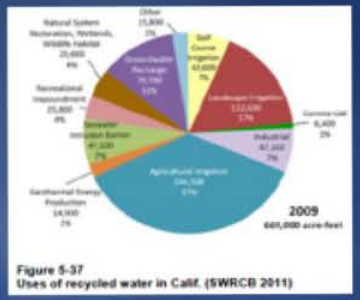


Figure 5-37
Uses of recycled water in Calif. (SWRCB 2011)

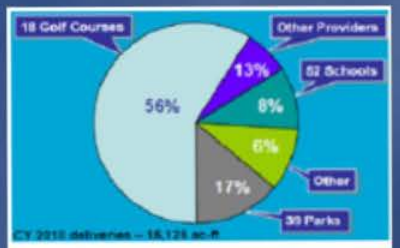


Figure 5-36
2010 Reclaimed water use in Tucson, Ariz.

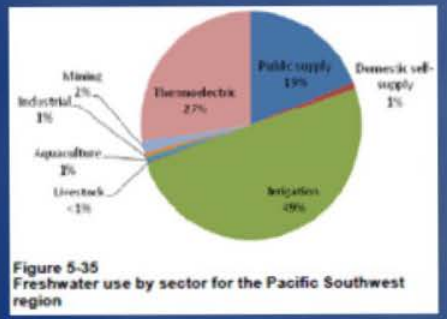


Figure 5-35
Freshwater use by sector for the Pacific Southwest region

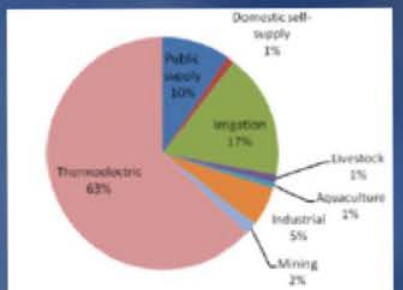


Figure 5-17
Freshwater use by sector for the Midwest and Great Lakes region

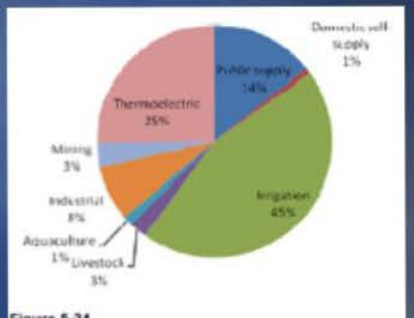


Figure 5-24
Freshwater use by sector for the South Central region

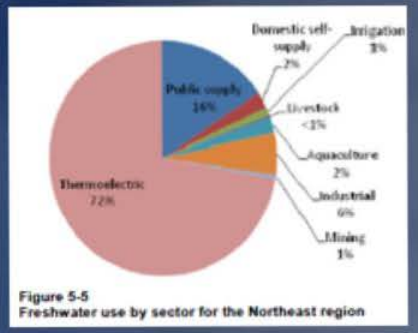


Figure 5-5
Freshwater use by sector for the Northeast region

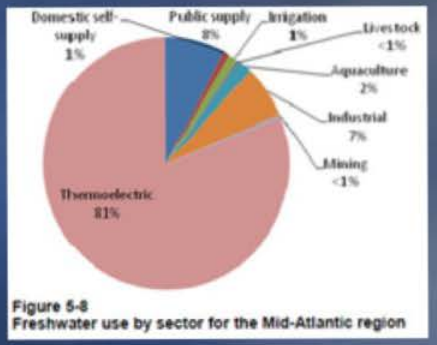


Figure 5-8
Freshwater use by sector for the Mid-Atlantic region

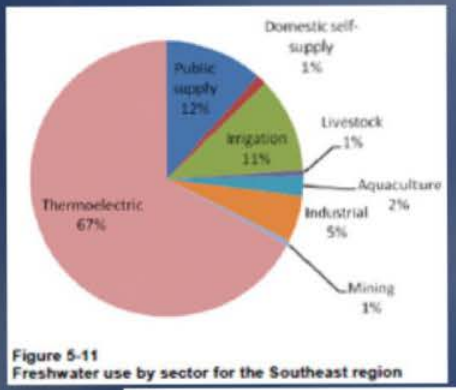


Figure 5-11
Freshwater use by sector for the Southeast region

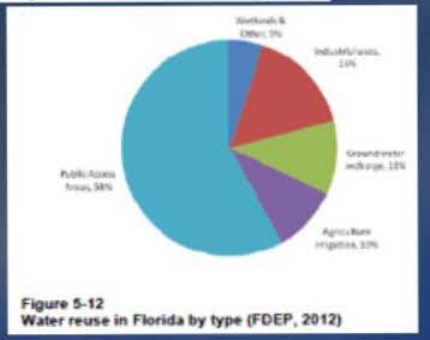


Figure 5-12
Water reuse in Florida by type (FDEP, 2012)

Mid-Atlantic: Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia

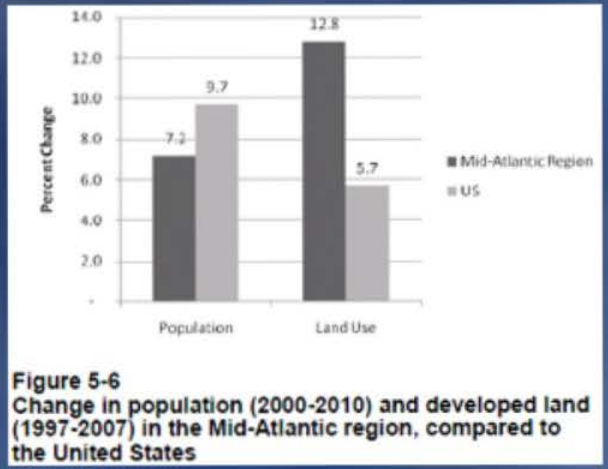


Figure 5-6
Change in population (2000-2010) and developed land (1997-2007) in the Mid-Atlantic region, compared to the United States

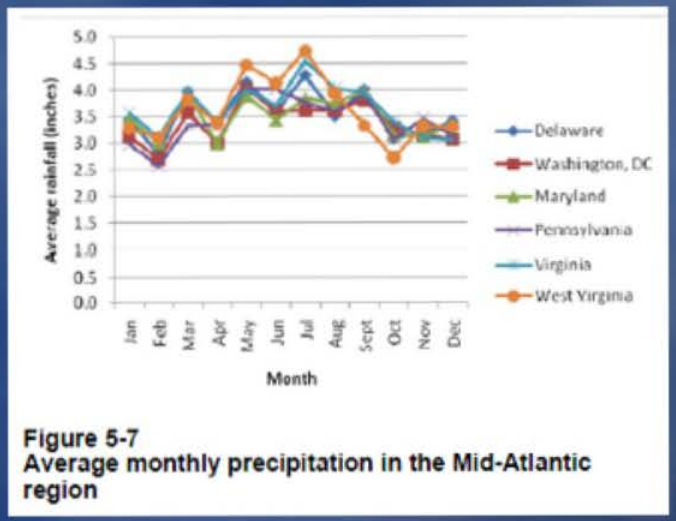


Figure 5-7
Average monthly precipitation in the Mid-Atlantic region

5.2.2.3 Water Use by Sector

Figure 5-8 shows freshwater use by sector in the Mid-Atlantic Region.

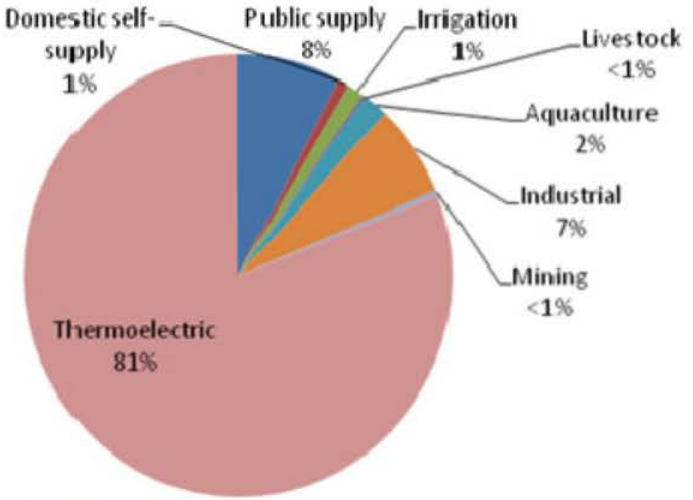


Figure 5-8
Freshwater use by sector for the Mid-Atlantic region

Pacific Northwest: Idaho, Oregon, Washington and Alaska

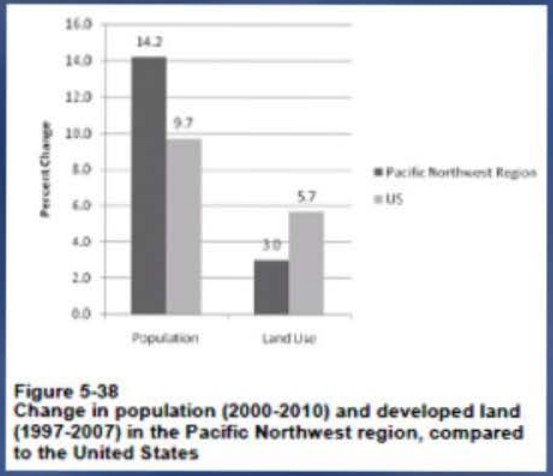


Figure 5-38
Change in population (2000-2010) and developed land (1997-2007) in the Pacific Northwest region, compared to the United States

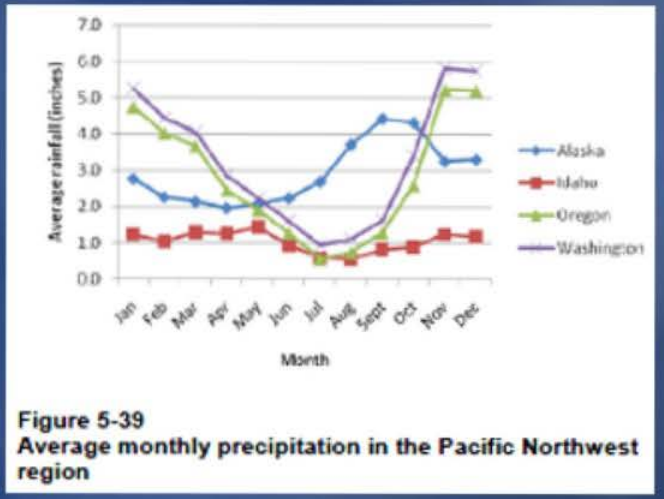


Figure 5-39
Average monthly precipitation in the Pacific Northwest region

5.2.8.3 Water Use by Sector

Figure 5-40 shows freshwater use by sector in the Pacific Northwest.

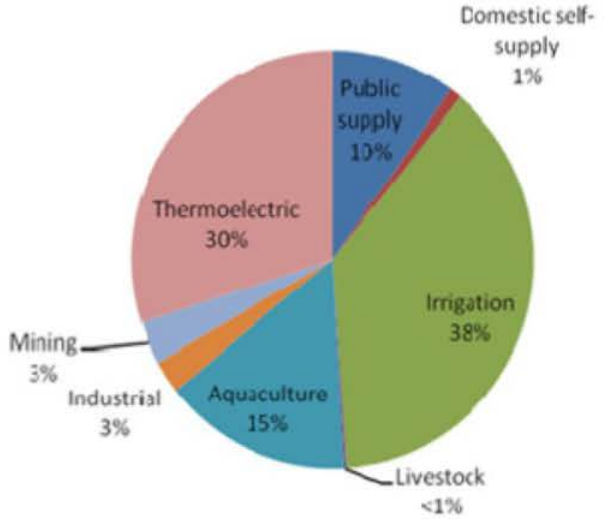


Figure 5-40
Freshwater use by sector for the Pacific Northwest region

Pacific Southwest: Arizona, California, Hawaii, Nevada, and Pacific Territories

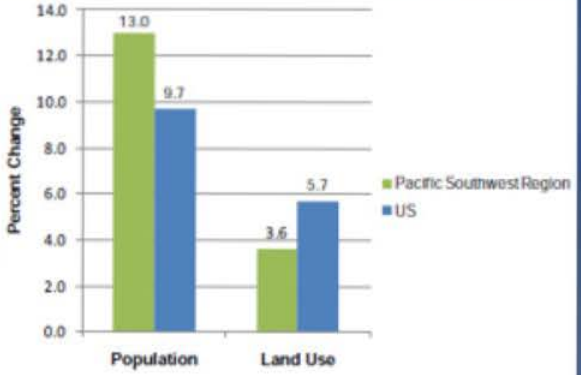


Figure 5-33
Change in population (2000-2010) and developed land (1997-2007) in the Pacific Southwest region, compared to the United States

5.2.7.2 Precipitation and Climate

Figure 5-34 depicts average monthly precipitation in the states of the Pacific Southwest—Arizona, California, Hawaii, and Nevada.

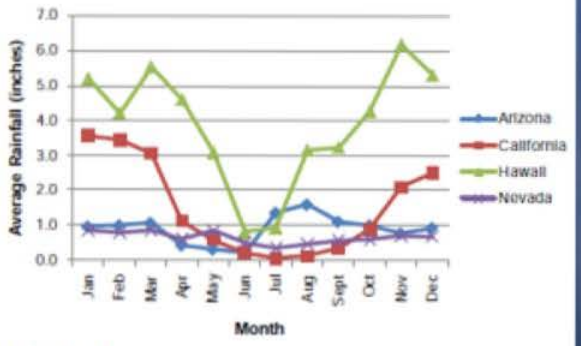


Figure 5-34
Average monthly precipitation in the Pacific Southwest region

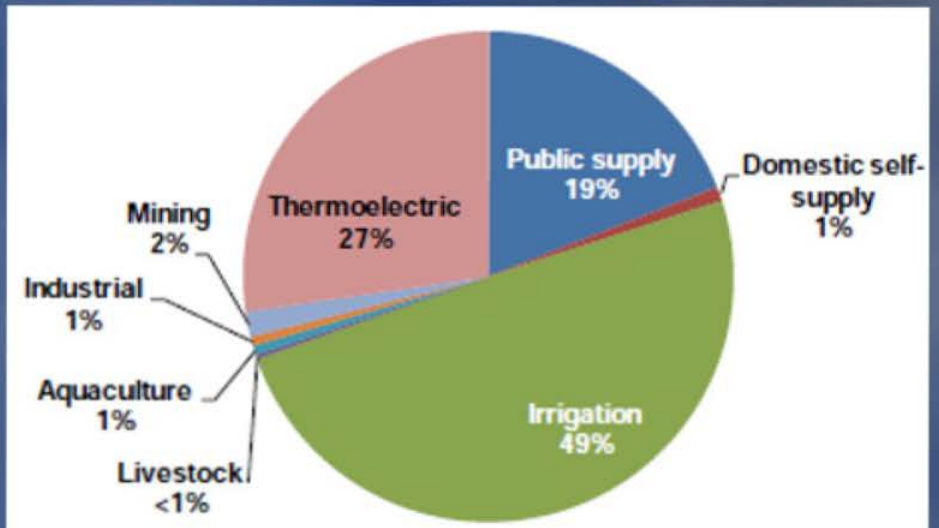


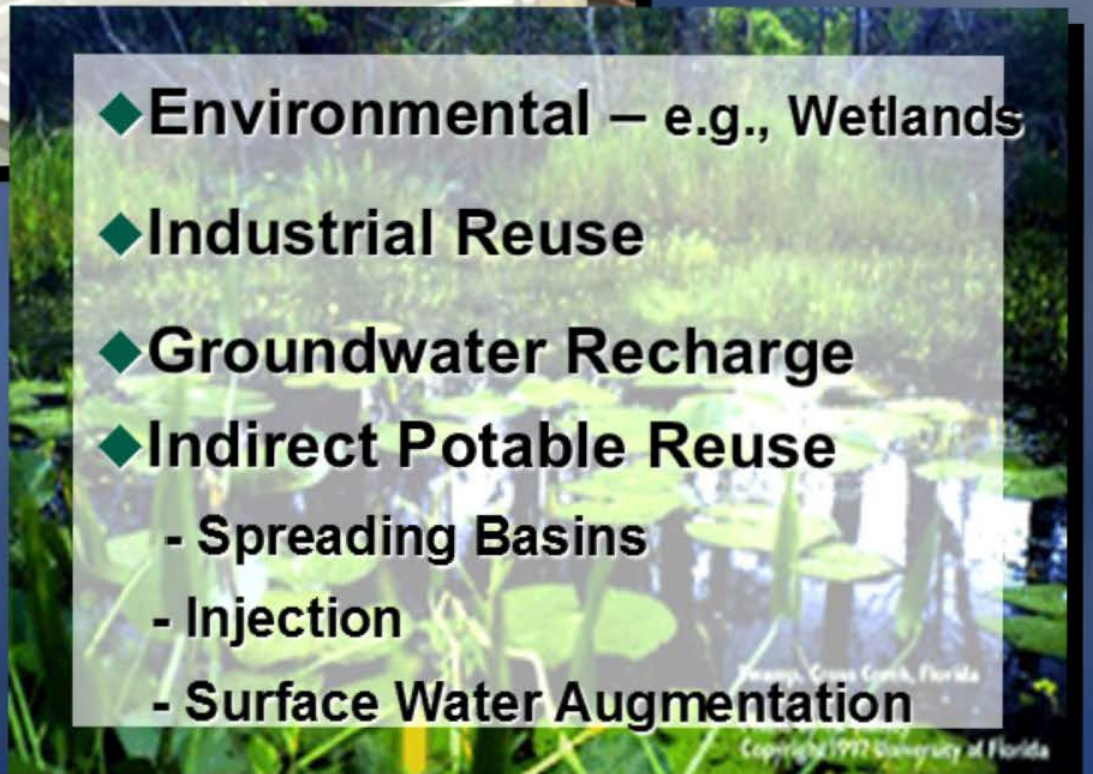
Figure 5-35
Freshwater use by sector for the Pacific Southwest region


THIS FIXTURE USES
NON-POTABLE RECLAIMED
WATER-DO NOT DRINK

Reuse Categories

- Unrestricted Urban Reuse
- Restricted Urban Reuse
- Agricultural Reuse for Food Crops
- Agricultural Reuse for Nonfood Crops
- Recreational Impoundments
- Intrusion Barrier

- Environmental – e.g., Wetlands
- Industrial Reuse
- Groundwater Recharge
- Indirect Potable Reuse
  - Spreading Basins
  - Injection
  - Surface Water Augmentation



Urban Reuse

- Landscape irrigation
- Golf course irrigation
- Commercial uses
- Decorative water features
- Fire prevention
- Toilet and urinal flushing
- Other nonpotable uses

Regulations and Guidelines Vary Depending on Type of Reuse

Indirect potable reuse

Agricultural Reuse on Food Crops

Unrestricted Recreational Reuse

Unrestricted Urban Irrigation Reuse

Restricted Urban Irrigation Reuse

Restricted Recreational Reuse

Industrial Reuse

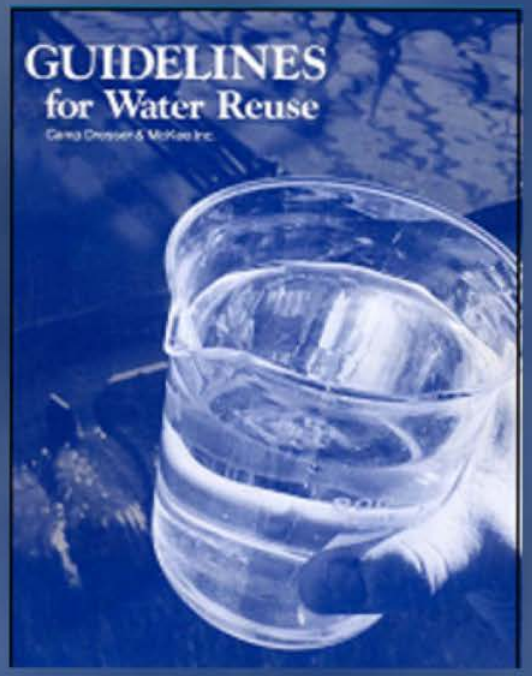
Environmental Reuse

Agricultural Reuse on Non-food Crops

More Stringent Regulations

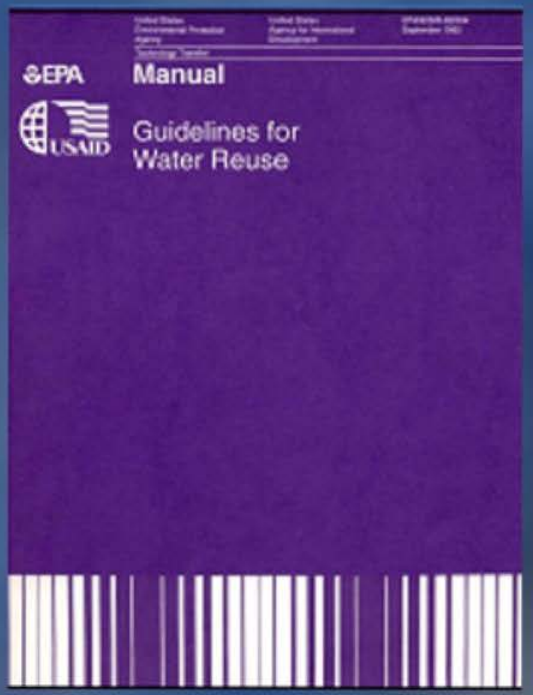
Less Stringent Regulations

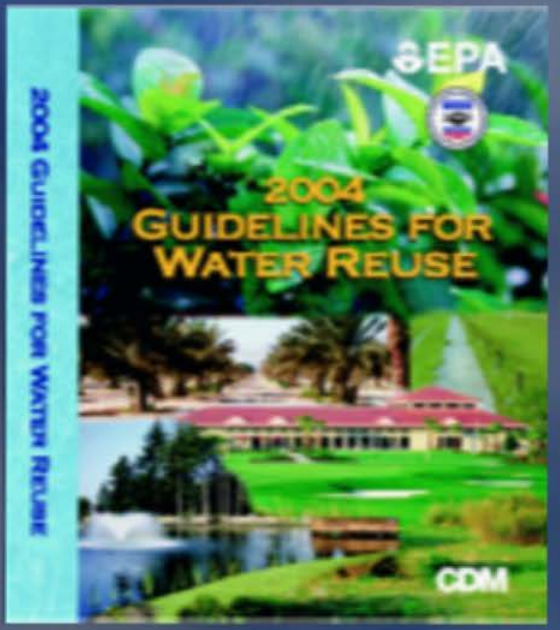
U.S. Guidelines on Water Reuse



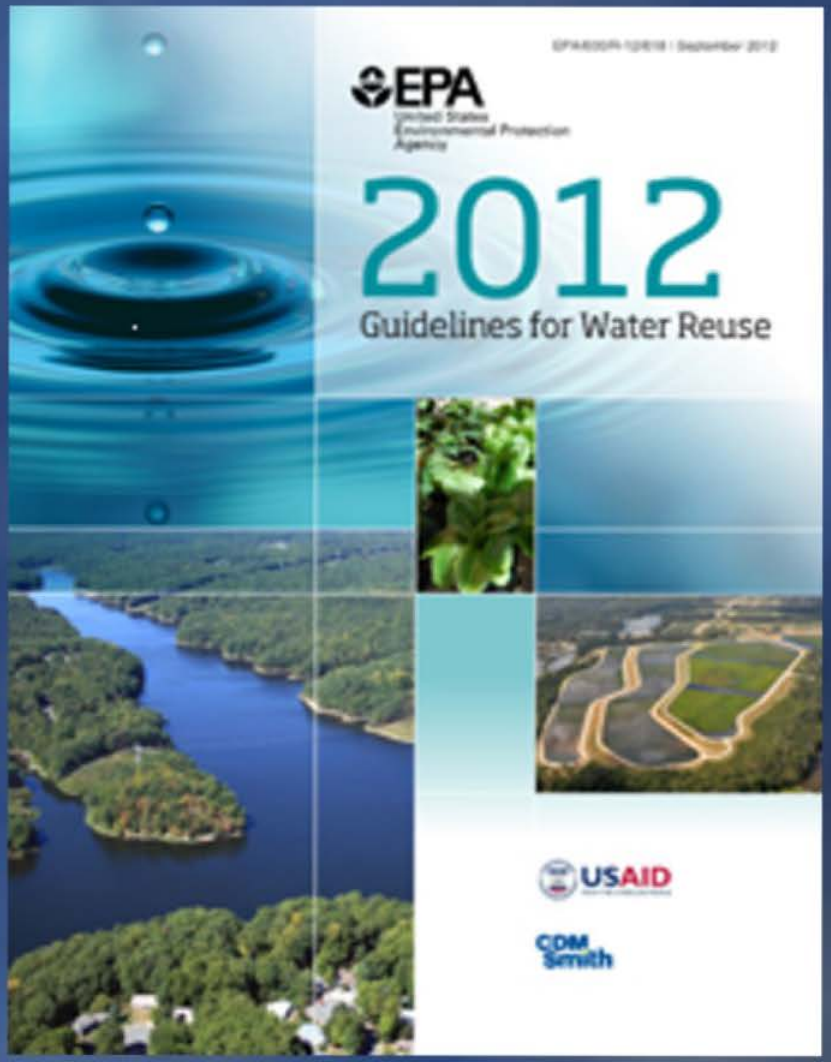
1980

1982





2004



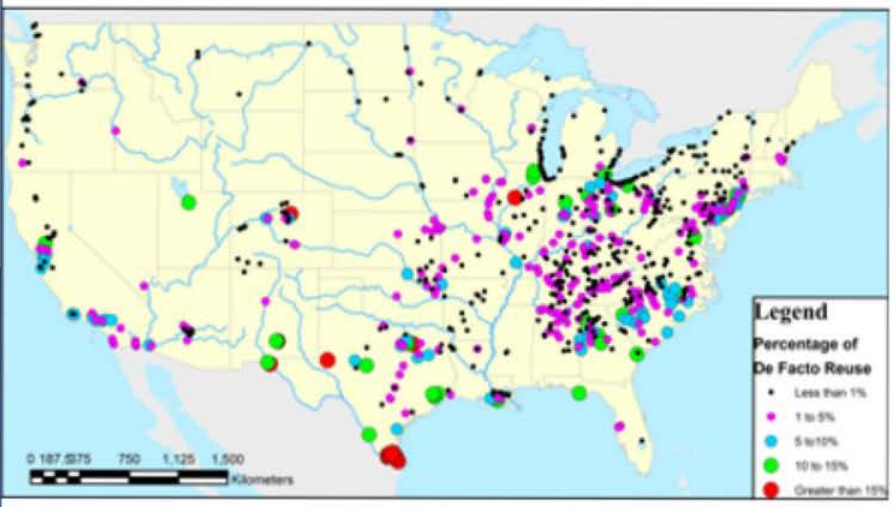
2012 EPA *Guidelines for Water Reuse*

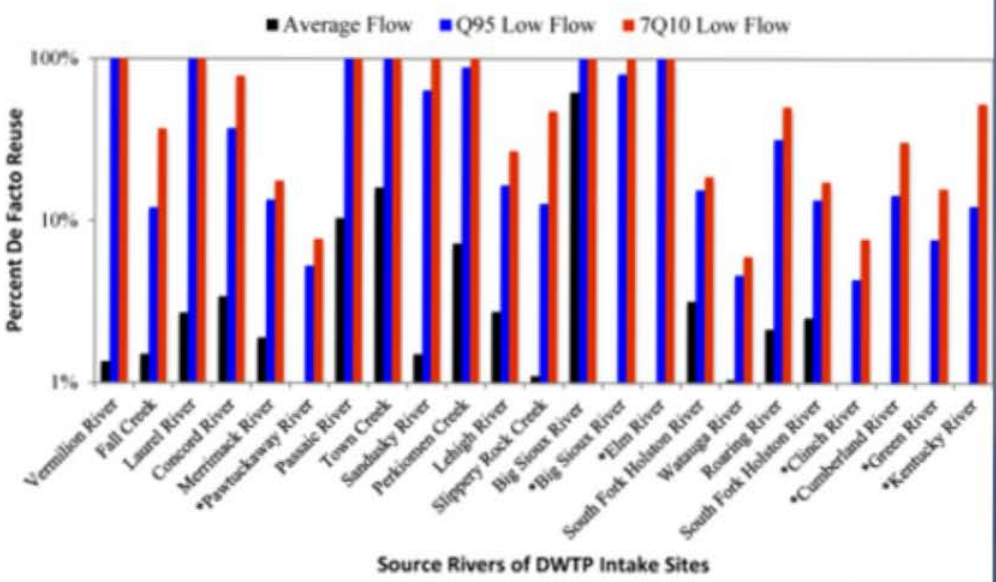
Table 4-3 Water reuse categories and number of states with rules, regulations or guidelines addressing these reuse categories [1]

Category of reuse		Description	Number of States or Territories with Rules, Regulations, or Guidelines Addressing Reuse Category
Urban Reuse	Unrestricted	The use of reclaimed water for nonpotable applications in municipal settings where public access is not restricted	32
	Restricted	The use of reclaimed water for nonpotable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction	40
Agricultural Reuse	Food Crops	The use of reclaimed water to irrigate food crops that are intended for human consumption	27
	Processed Food Crops and Non-food Crops	The use of reclaimed water to irrigate crops that are either processed before human consumption or not consumed by humans	43
Impoundments	Unrestricted	The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities (some states categorize snowmaking in this category)	13
	Restricted	The use of reclaimed water in an impoundment where body contact is restricted (some states include fishing and boating in this category)	17
Environmental Reuse		The use of reclaimed water to create, enhance, sustain, or augment water bodies, including wetlands, aquatic habitats, or stream flow	17
Industrial Reuse		The use of reclaimed water in industrial applications and facilities, power production, and extraction of fossil fuels	31
Groundwater Recharge – Nonpotable Reuse		The use of reclaimed water to recharge aquifers that are not used as a potablewater source	16
Potable Reuse	Indirect Potable Reuse (IPR)	Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment	9
	Direct Potable Reuse (DPR)	The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a water treatment plant, either collocated or remote from the advanced wastewater treatment system	0

[1] Individual state reuse programs often incorporate different terminology so the reader should exercise caution in comparing the categories in these tables directly to state regulatory definitions

UNPLANNED *(de facto)* potable water reuse





"The NAE report stated that de facto reuse with 5% treated wastewater posed higher risks from wastewater contaminants than planned potable reuse schemes."

Source: Rice and Westerhoff (2015) *Environ. Sci. Technol.* 49 (2) 982-989.

Percent Opposed to Uses of Effluent

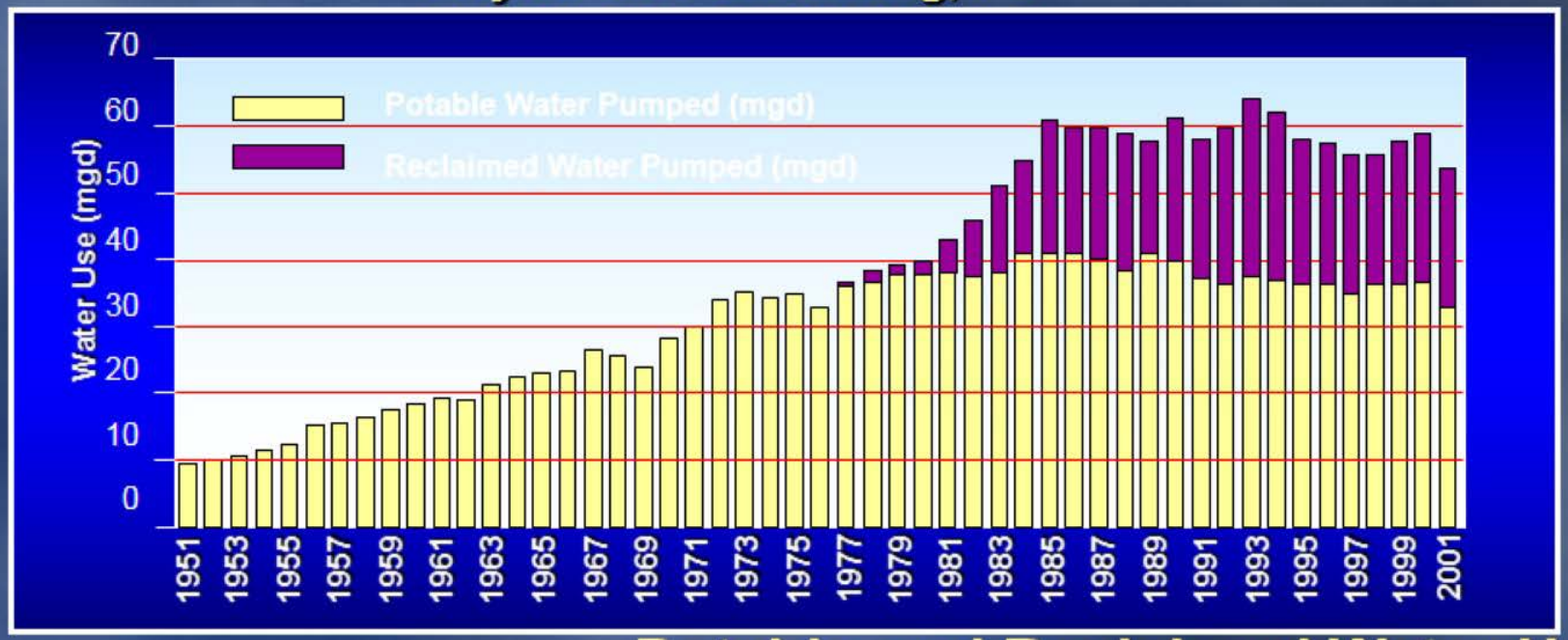
Type of Reuse	General Options Survey (%)
Drinking Water	54
Bathing in the home	33
Swimming	21
Irrigation of dairy pasture	14
Orchard irrigation	10
Residential irrigation	4
Golf course irrigation	3
Road construction	2

Source: Bruvold, 1988

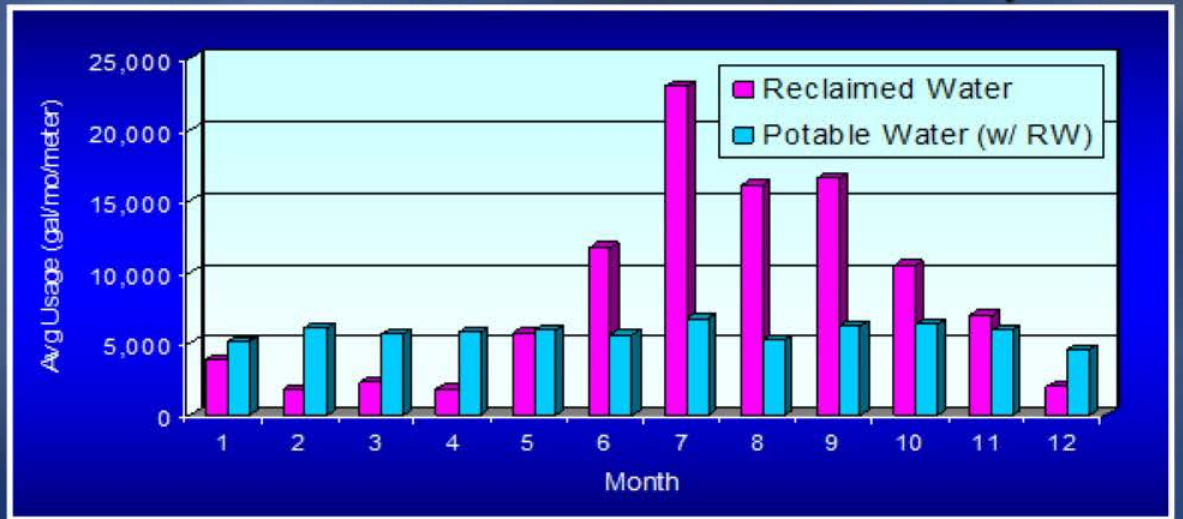

IRRIGATION WITH
RECLAIMED WATER
DO NOT DRINK
AVISO... AGUA RECICLADA
SE PROHIBE BEBER


56
IRRIGATION WATER
NOT FOR DRINKING
AGUA PARA RIEGO
NO PARA TOMAR

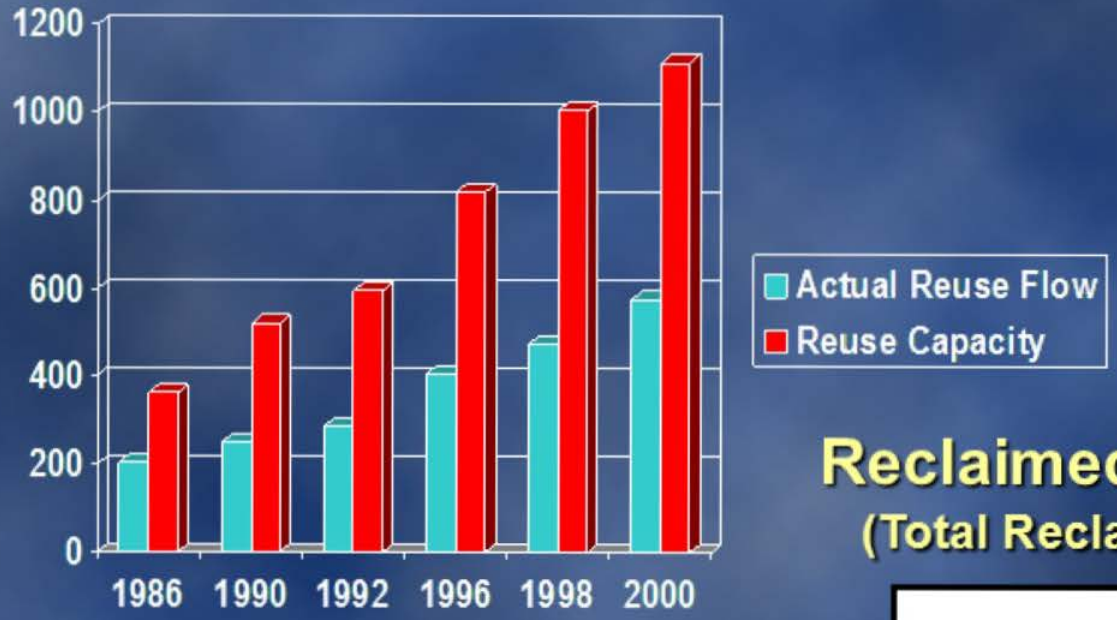
Potable and Reclaimed Water Usage
City of St. Petersburg, FL



Potable and Reclaimed Water Use
in a North Carolina Residential Development

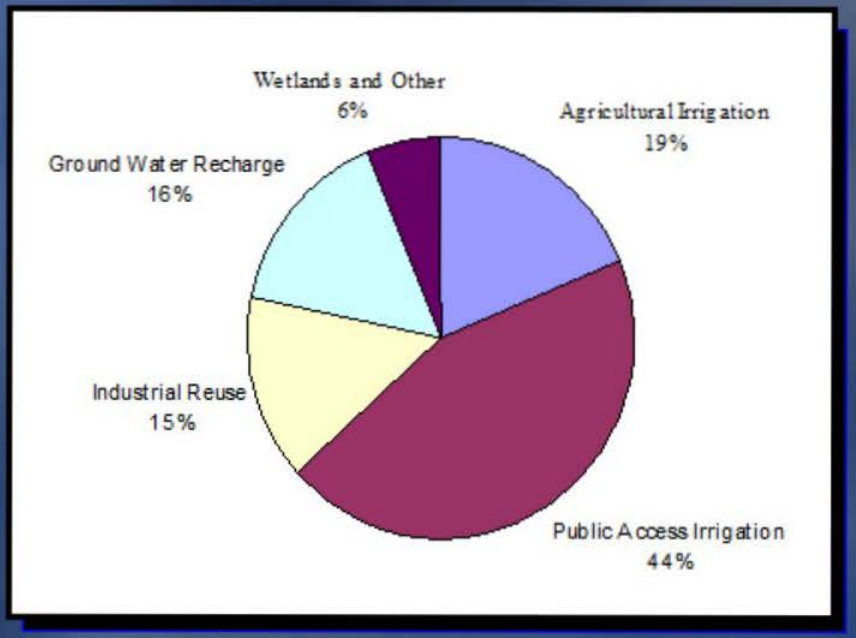


Florida's Recent Reuse History

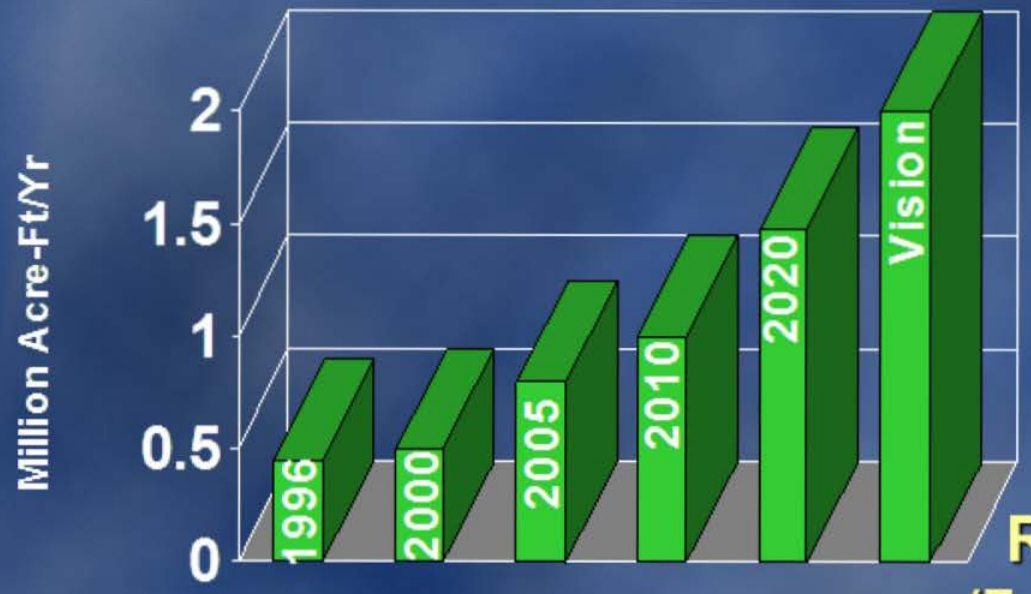


Reclaimed Water Use in Florida

(Total Reclaimed Water Flow = 575mgd)

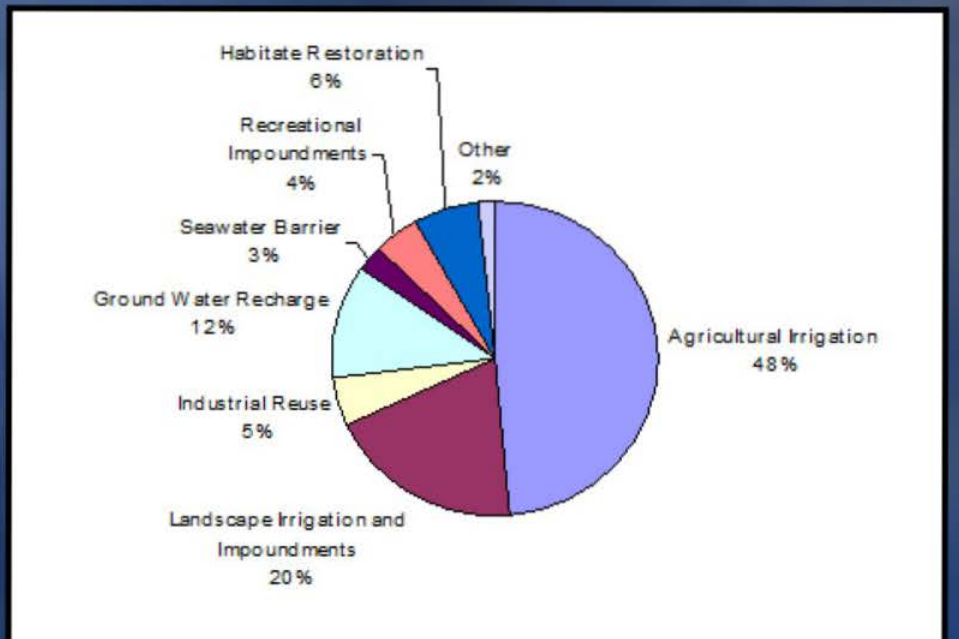


California Water Recycling Potential

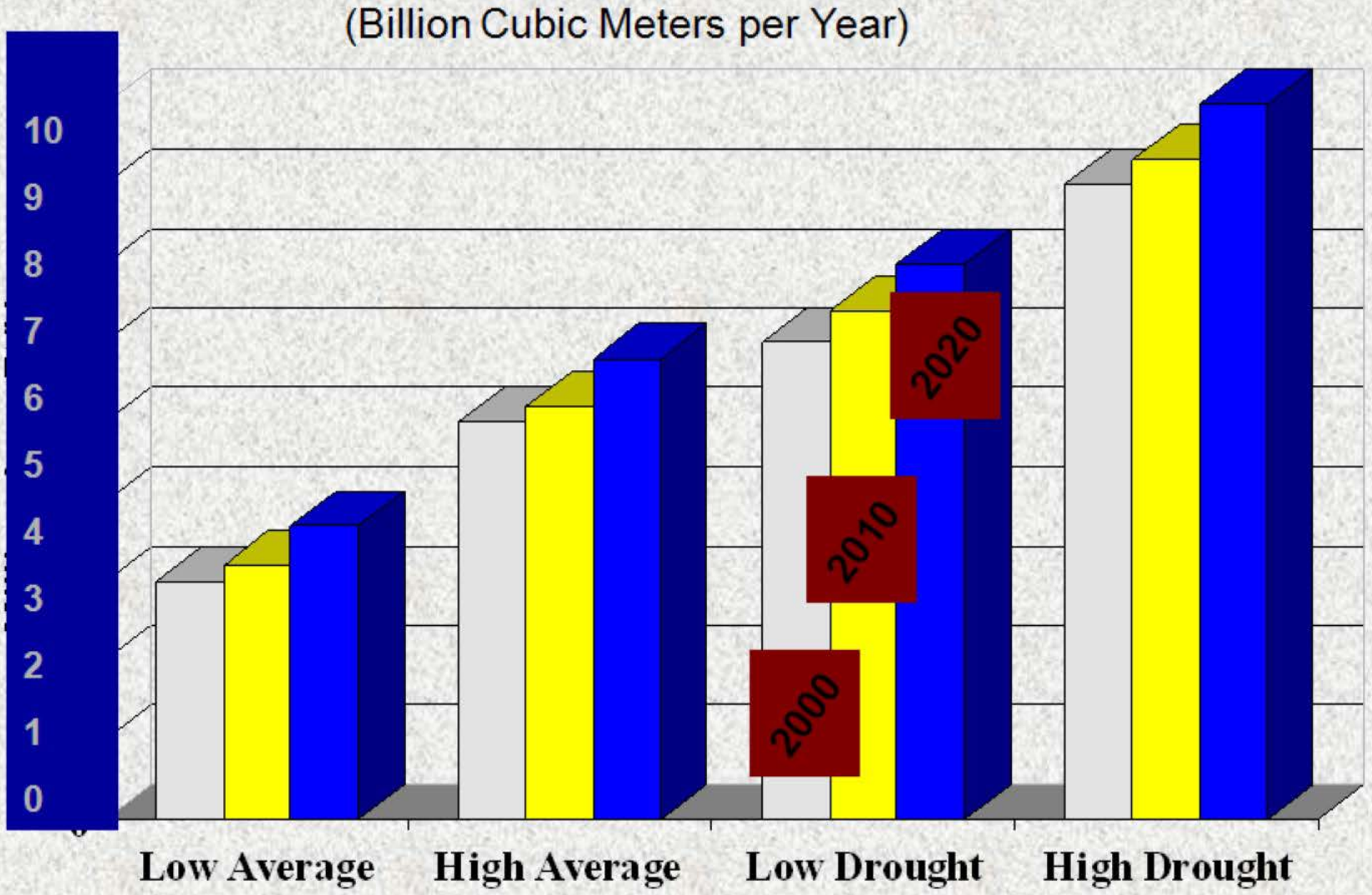


Reclaimed Water Use in CA

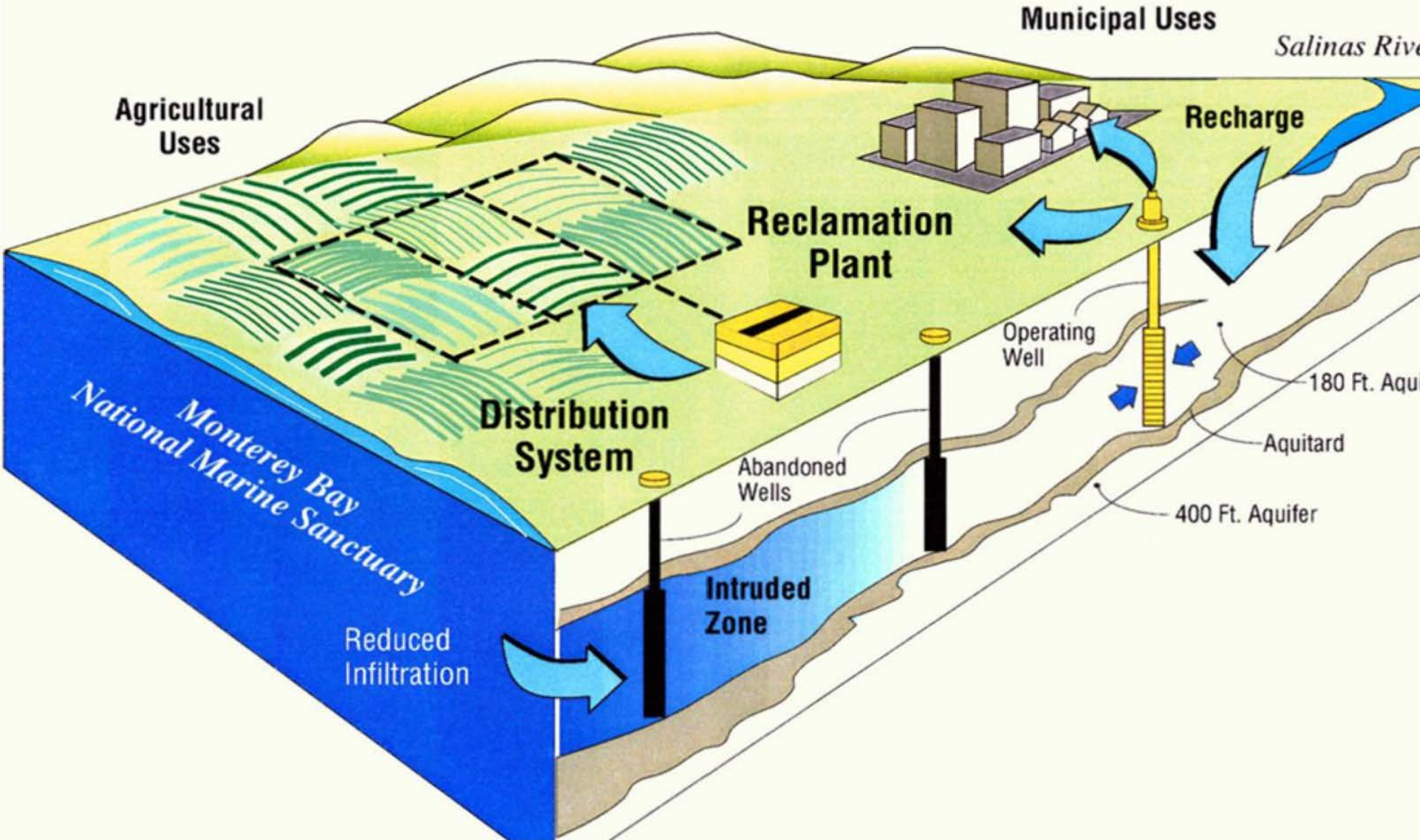
(Total Reclaimed Water Flow = 358 mgd)



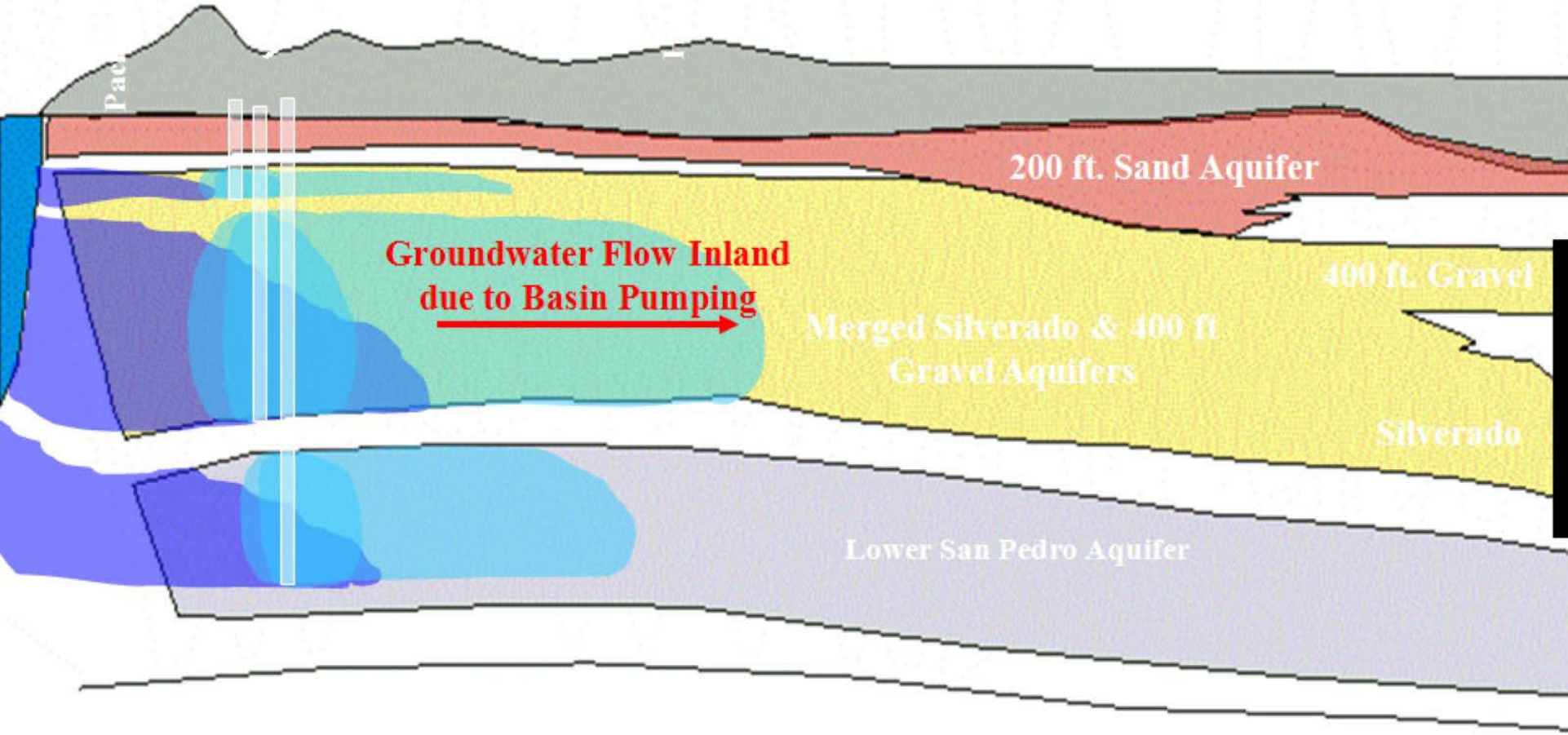
California Water Shortage



Development of the Reclamation Concept



Seawater Intrusion Barrier




3. 10. 2000 13:28

Technical Issues and Public Concerns Remain

- Constant effluent supply vs variable demand
- Reliability of treatment systems to assure high quality at all times
- Water quality issues
  - disinfection by-products, trace amounts of NDMAs, pharmaceuticals, endocrine disrupters, emerging pathogens, etc.
- Public opinion/acceptance barriers
  - human origin (the "Yuck" factor)
  - industrial input & household products

GWR System (OCWD and OCSD)
Advanced Water Treatment Flow Diagram

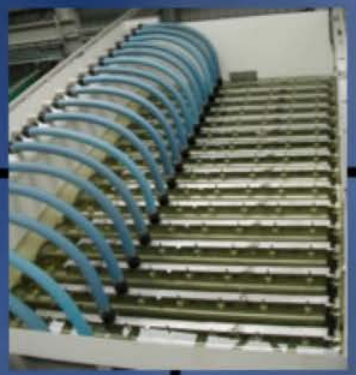
Enhanced Source Control

Secondary Treatment

OCSD Secondary Effluent

86 mgd

Microfiltration (MF)



Backwash OCSD Plant 1

70 mgd

Reverse Osmosis (RO)

Brine OCSD Outfall

70 mgd

Ultraviolet Light (AOP)

with hydrogen peroxide

Purified Water

Natural soil filtration

MICROFILTRATION, CARTRIDGE FILTERS, REVERSE OSMOSIS, AND ADVANCED (UV) OXIDATION AT OCWD

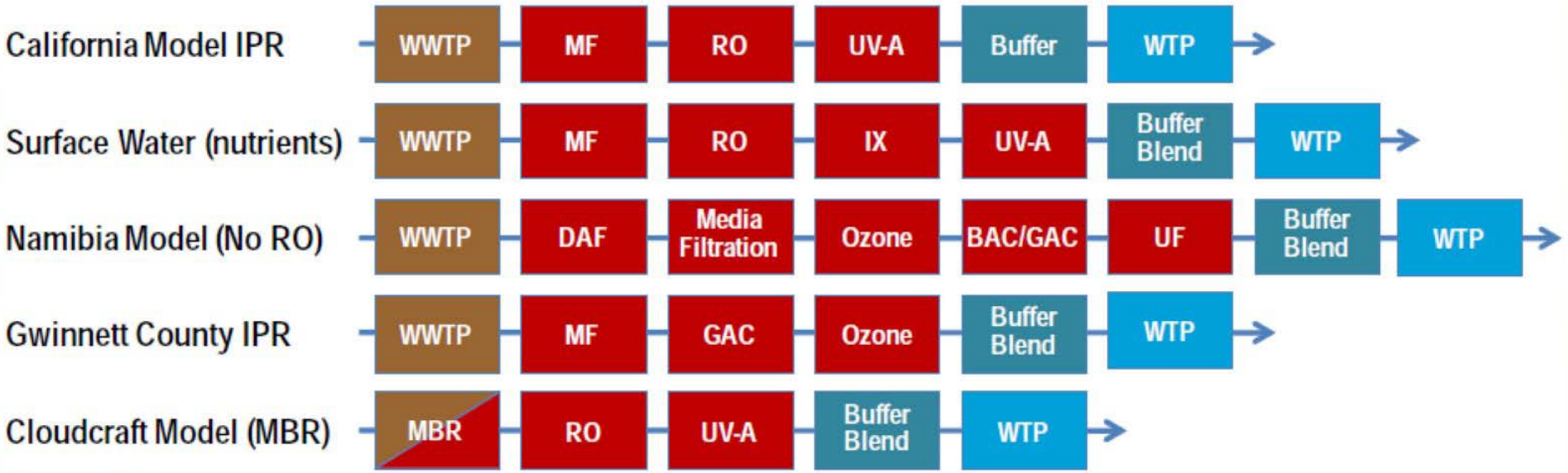


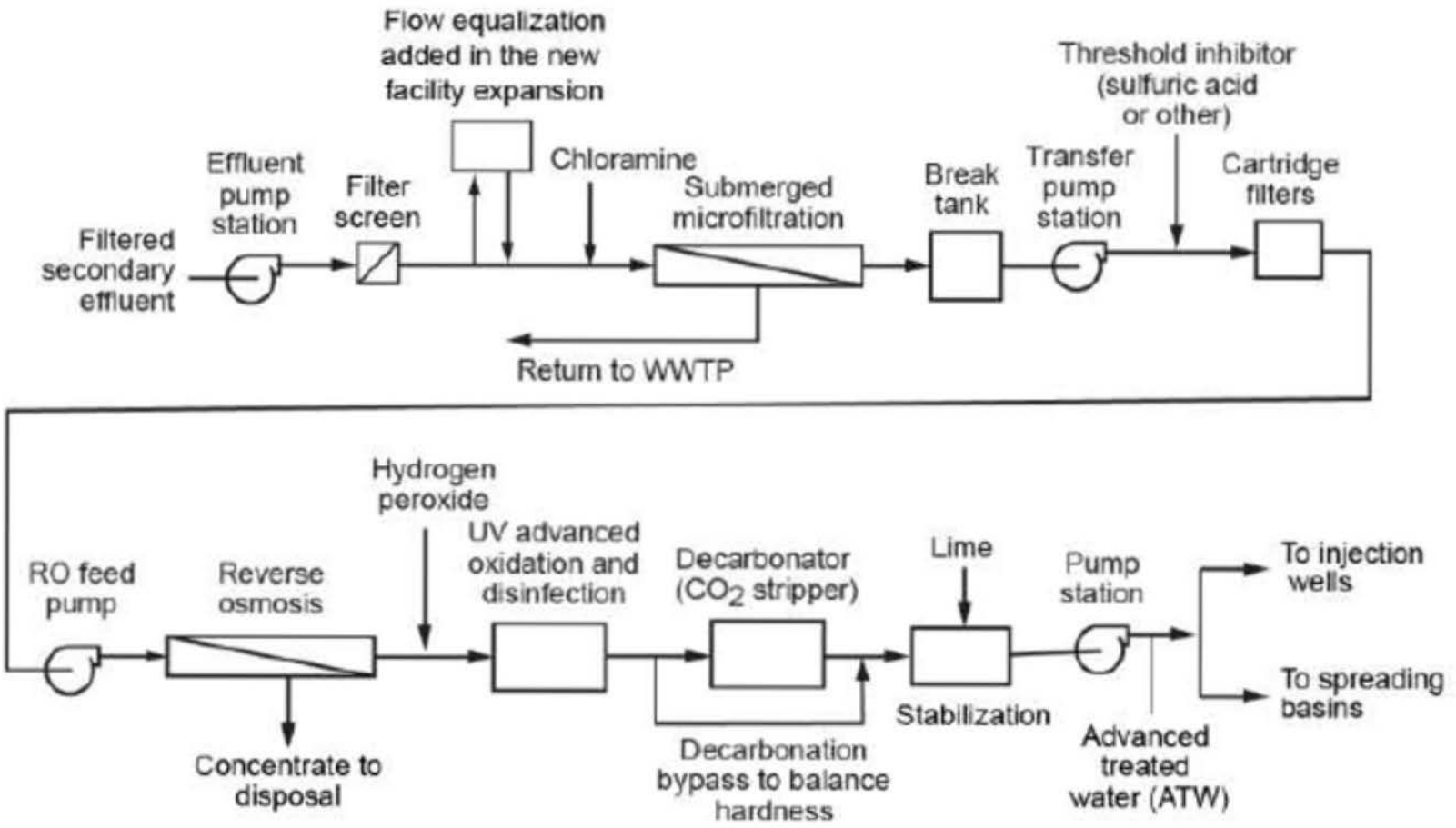
Figure 6-1
Potable reuse treatment scenarios (Chalmers et al., 2011)

Regardless of the end use and desired reclaimed water quality there are technologies available to treat water to whatever level is required for the targeted end use. In addition to successful implementation of current advanced treatment technologies for producing reclaimed water, there is ongoing research into optimizing these processes and investigating emerging technologies to meet treatment objectives for both pathogens and chemical constituents.

Potable reuse reports & themes

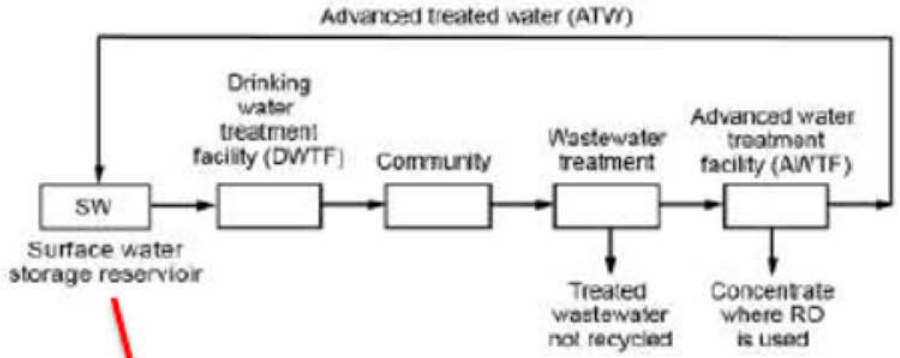
	Nickname	Year	US overview	Chemicals	Pathogens	Risk Assess.	Reg. Summ.	Treatment	Source Ctrl.	Buffers	Monitoring	Operations	Cost	Epidemio.	Public	Research	Case studies
1	WEF/AWWA	2008		✓	✓		✓	✓				✓			✓		✓
2	NWRI - A Path Forward	2011						✓	✓	✓	✓				✓	✓	✓
3	NRC	2012	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
4	State of the Science Report and Equivalency Criteria for Treatment Trains (WRRF 11-02-2)	2013		✓	✓		✓	✓		✓	✓					✓	✓
5	Australian Academy of Technological Sciences and Engineering – Australia-specific	2013	✓	✓	✓		✓	✓		✓			✓	✓	✓		✓
6	Direct Potable Reuse Resource Document (TWDB) – Texas-specific	2015		✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	
7	Framework for Direct Potable Reuse (AWWA, NWRI, WEF, and WateReuse)	2015				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
8	EPA Potable Reuse Supplement	2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

TECHNOLOGIES FOR THE INDIRECT AND DIRECT POTABLE REUSE



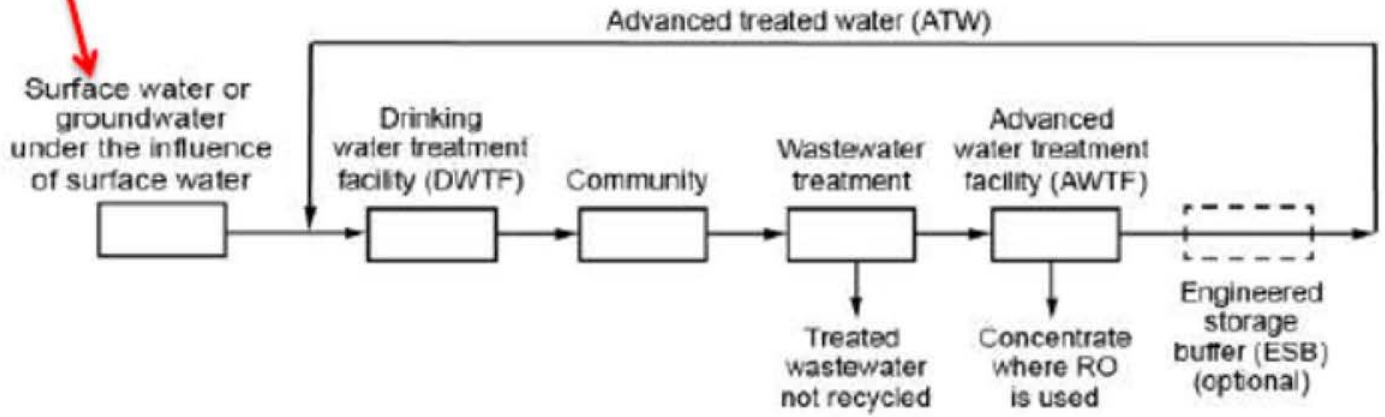
Adapted from OCWD

INDIRECT VERSUS DIRECT POTABLE REUSE



Indirect potable reuse (IPR)

San Vicente reservoir, San Diego, CA



Direct potable reuse (DPR)

Alternative treatment trains

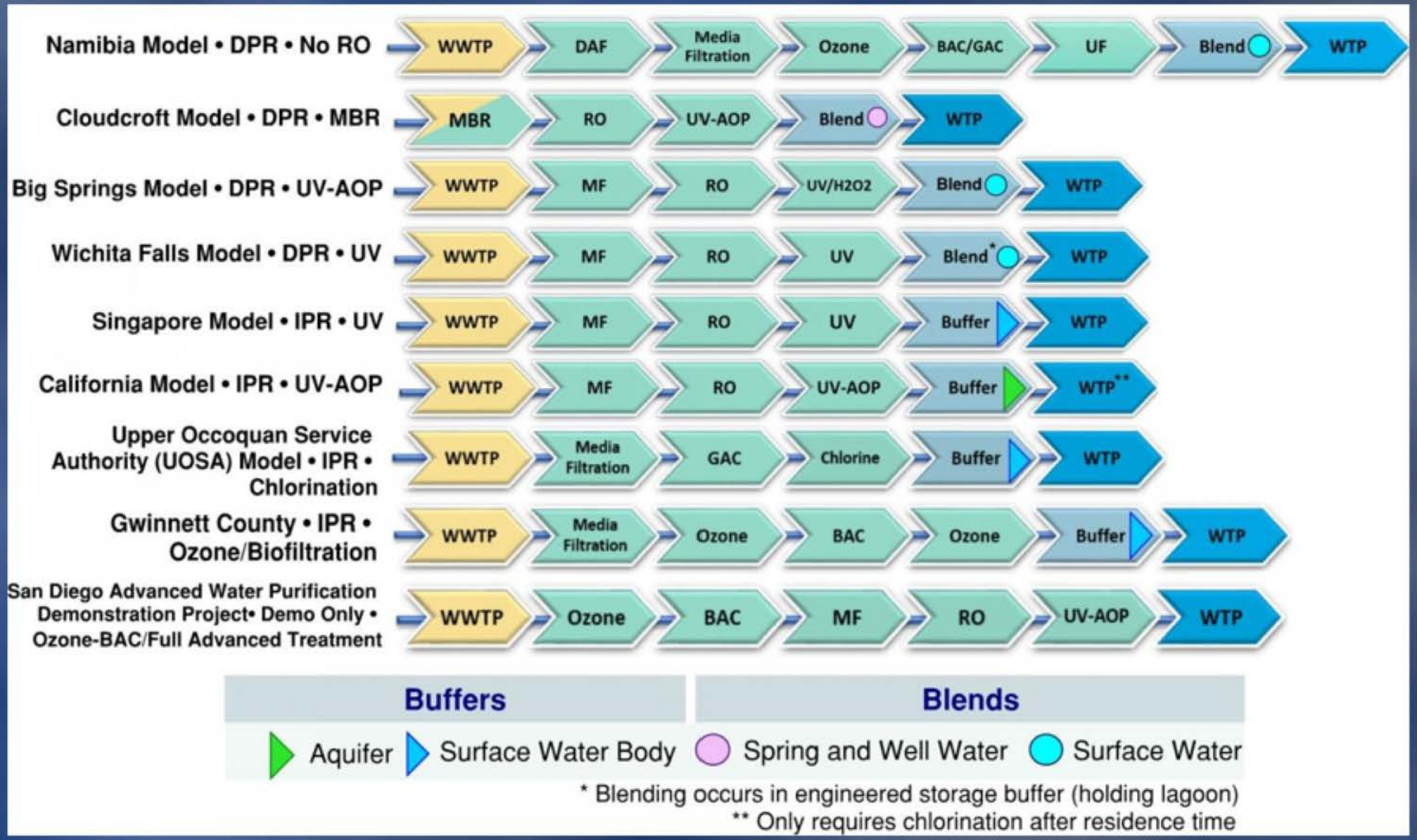


Table 6-6 Summary of filter type characteristics[1]

Filter Type	Filtration Driving Force	Nominal Pore Size, *um*	Contaminants targeted for removal
Depth			
Non-Compressible Media	Gravity or pressure differential	60-300	TSS, turbidity, some protozoan oocysts and cysts
Compressible Media			
Surface Filtration			
Surface Filtration	Gravity	5-20	TSS, turbidity, some protozoan oocysts and cysts
Membrane[2]			
Microfiltration	Pressure differential	0.05	TSS, turbidity, some protozoan oocysts and cysts, some bacteria and viruses
Ultrafiltration	Pressure differential	0.002-0.050	Macromolecules, colloids, most bacteria, some viruses, proteins
Nanofiltration	Pressure differential	<0.002	Small molecules, some hardness, viruses
Reverse Osmosis	Pressure differential	<0.002	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions

[1] Information taken from California Department of Public Health (2012), Metcalf & Eddy (2003)

[2] Information from *Water Treatment Membrane Processes* (AWWA, 1996)

Table 6-3 Indicative log removals of indicator microorganisms and enteric pathogens during various stages of wastewater treatment

	Indicator microorganisms			Pathogenic microorganisms				
Type of Microorganism	*Escherichia coli* (indicator bacteria)	*Clostridium perfringens*	Phage (indicator virus)	Enteric bacteria (e.g., *Campylobacter*)	Enteric viruses	*Giardia lamblia*	*Cryptosporidium parvum*	Helminths
Bacteria	X	X		X				
Protozoa and helminths						X	X	X
Viruses			X		X			
Indicative Log Reductions in Various Stages of Wastewater Treatment[1]								
Secondary treatment	1 - 3	0.5 - 1	0.5 - 2.5	1 - 3	0.5 - 2	0.5 - 1.5	0.5 - 1	0 - 2
Dual media filtration[2]	0 - 1	0 - 1	1 - 4	0 - 1	0.5 - 3	1 - 3	1.5 - 2.5	2 - 3
Membrane filtration (UF, NF, and RO)[3]	4 - >6	>6	2 - >6	>6	2 - >6	>6	4 - >6	>6
Reservoir storage	1 - 5	N/A	1 - 4	1 - 5	1 - 4	3 - 4	1 - 3.5	1.5 - >3
Ozonation	2 - 6	0 - 0.5	2 - 6	2 - 6	3 - 6	2 - 4	1 - 2	N/A
UV disinfection	2 - >6	N/A	3 - >6	2 - >6	1 ->6	3 - >6	3 - >6	N/A
Advanced oxidation	>6	N/A	>6	>6	>6	>6	>6	N/A
Chlorination	2 - >6	1 - 2	0 - 2.5	2 - >6	1 - 3	0.5 - 1.5	0 - 0.5	0 – 1

(Sources: Bitton, 1999; EPHC, 2008; Mara and Horan, 2003; NRC, 1998; NRC, 2012; Rose et al., 1996; Rose, et al., 2001; EPA, 1999, 2003, 2004; WHO, 1989)

[1]Reduction rates depend on specific operating conditions, such as retention times, contact times and concentrations of chemicals used, pore size, filter depths, pretreatment, and other factors. Ranges given should not be used as design or regulatory bases—they are meant to show relative comparisons only.
[2]Including coagulation
[3]Removal rates vary dramatically depending on the installation and maintenance of the membranes.
N/A = not available

Table 6-4 Categories of trace chemical constituents (natural and synthetic) potentially detectable in reclaimed water and illustrative example chemicals (NRC, 2012)

End use Category	Examples
Industrial chemicals	1,4-Dioxane, perflurooctanoic acid, methyl tertiary butyl ether, tetrachloroethane
Pesticides, biocides, and herbicides	Atrazine, lindane, diuron, fipronil
Natural chemicals	Hormones (17β-estradiol), phytoestrogens, geosmin, 2-methylisoborneol
Pharmaceuticals and metabolites	Antibacterials (sulfamethoxazole), analgesics (acetominophen, ibuprofen), beta-blockers (atenolol), antiepileptics (phenytoin, carbamazepine), veterinary and human antibiotics (azithromycin), oral contraceptives (ethinyl estradiol)
Personal care products	Triclosan, sunscreen ingredients, fragrances, pigments
Household chemicals and food additives	Sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perfluorooctane sulfonate)
Transformation products	NDMA, HAAs, and THMs

Table 6-5 Indicative percent removals of organic chemicals during various stages of wastewater treatment

Treatment	Percent Removal										
			Pharmaceuticals					Hormones			
	B(a)p	Antibiotics[1]	DZP	CBZ	DCF	IBP	PCT	Steroid[2]	Anabolic[3]	Fragrance	NDMA
Secondary (activated sludge)	nd	10–50	nd	–	10–50	>90	nd	>90	nd	50–90	–
Soil aquifer treatment	nd	nd	nd	25–50	>90	>90	>90	>90	nd	>90	>90
Aquifer storage	nd	50–90	10–50	–	50–90	50–90	Nd	>90	nd	–	–
Microfiltration	nd	<20	<20	<20	<20	<20	<20	<20	nd	<20	
Ultrafiltration/ powdered activated carbon (PAC)	nd	>90	>90	>90	>90	>90	nd	>90	nd	>90	>90
Nanofiltration	>80	50–80	50–80	50–80	50–80	50–80	50–80	50–80	50–80	50–80	
Reverse osmosis	>80	>95	>95	>95	>95	>95	>95	>95	>95	>95	25–50
PAC	>80	20–>80	50–80	50–80	20–50	<20	50–80	50–80	50–80	50–80	
Granular activated carbon		>90	>90	>90	>90	>90		>90		>90	>90
Ozonation	>80	>95	50–80	50–80	>95	50–80	>95	>95	>80	50–90	50–90
Advanced oxidation		50–80	50–80	>80	>80	>80	>80	>80	>80	50–80	>90
High-level ultraviolet		20–>80	<20	20–50	>80	20–50	>80	>80	20–50	nd	>90
Chlorination	>80	>80	20–50	–<20	>80	<20	>80	>80	<20	20–>80	–
Chloramination	50–80	<20	<20	<20	50–80	<20	>80	>80	<20	<20	

(Sources: Ternes and Joss, 2006; Snyder et al., 2010)

B(a)p = benz(a)pyrene; CBZ = carbamazepine, DBP = disinfection by-product; DCF = diclofenac; DZP = diazepam; IBP = ibuprofen; NDMA=N-nitrosodimethylamine; nd = no data; PAC = powdered activated carbon; PCT = paracetamol.

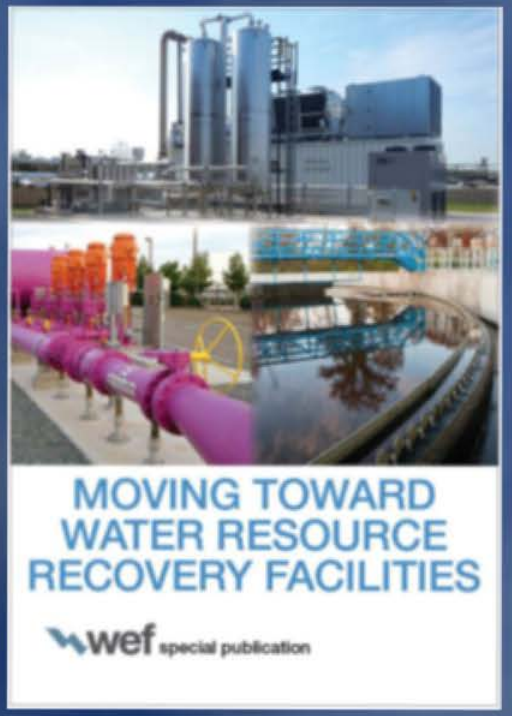
[1] erythromycin, sulfamethoxazole, triclosan, trimethoprim

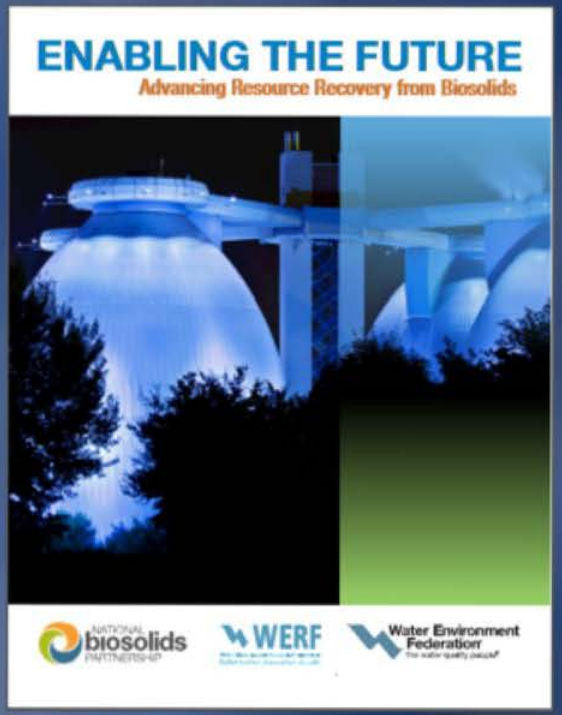
[2] ethynylestradiol; estrone, estradiol and estriol

[3] progesterone, testosterone

Disinfection alternatives to chlorine

- Mature technologies (UV and ozone) have been a focus of research, resulting in improvements in system efficiency
- Innovative and emerging technologies
  - Peracetic acid
  - Pasteurization
  - Ferrate





Energy:
- Biogas
- Biofuels
- Heat Recovery
- Hydropower
- Microbial Fuel Cells

Water:
- "Fit for Purpose" Water
- Non-potable Reuse
- Indirect Potable Reuse
- Direct Potable Reuse

Material Recovery:
- Nitrogen Recovery
- Phosphorus Recovery
- Enhanced Fertilizer Production
- Biodegradable Plastics
- Methanol Replacement for BNR Processes