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A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution

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General Abbreviations and Acronyms

BNR	biological nutrient removal
BMP	best management practice
ENR	enhanced nutrient removal
EPA	[United States] Environmental Protection Agency
gpd	gallons per day
HAB	harmful algal bloom
lb	pound
µg/L	micrograms per liter
mg/L	milligrams per liter
mgd	million gallons per day
MLE	modified Ludzack-Ettinger
O&M	operations and maintenance
QAPP	quality assurance project plan
TA	total ammonia nitrogen
TIN	total inorganic nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorous
TSS	total suspended solids
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

Nutrient pollution, defined as excess amounts of nitrogen and phosphorus in aquatic systems, is one of the leading causes of water quality impairment in the United States. This report compiles current information regarding the costs of nutrient pollution. Such costs may be of two broad types. Some costs are associated with reducing nutrient pollution at its sources. Other costs are associated with the impacts of nutrient pollution in the environment. The latter category of costs is referred to as "external costs" or "externalities," because they are "external" to the owners of the farms, businesses, or facilities that generate them.

The data in this compilation were collected from a range of sources including published, peer-reviewed journals, government-funded research and reports, academic studies and other data sources that met data quality objectives and procedures set forth in this report as described in the Methods section. This report provides users with a collection of other researchers' data from 2000 through 2012 as well as references to the literature cited. The U.S. Environmental Protection Agency's (EPA's) intent is to provide information that users can evaluate and use to form their own conclusions about appropriate management actions for controlling nutrient pollution in specific watersheds and waterbodies. Of course, readers should use caution and careful judgment in applying these results, as circumstances are rarely the same from one context to another. Moreover, as the report notes, not all estimates of monetary impacts can be directly translated into economically meaningful cost estimates.

Cost is a major factor in the management and control of nutrient pollution. External costs – costs borne by the public more generally – associated with the impacts from uncontrolled or under-controlled nutrient pollution and delayed action are important considerations. The adverse biological and ecological effects of nutrient pollution can result in economic losses across multiple industries and economic sectors. Managing and controlling nutrient pollution must also include consideration of the costs associated such actions, including the development, implementation, and enforcement of pollution control plans, wastewater treatment plant upgrades, municipal stormwater controls, agricultural best management practices, homeowner septic system improvements, and other actions.

Although it may not be appropriate to directly compare the costs of controlling nutrients to the economic impacts associated with nutrient pollution because the studies vary in their analyses, methodologies, starting conditions and initial assumptions, the document will help users to understand the substantial economic costs of *not* controlling nutrient pollution. The data and information compiled for this report are instructive in that they provide relative order of magnitude estimates appropriate for screening or feasibility analyses, and can be used to add perspective to the costs of not implementing controls. The information in this report may inform state, tribal, and local processes to develop policies and tools to reduce nutrient pollution. The information suggests that nitrogen and phosphorus may be expensive to control after they are released to the environment. Preventing them from entering the system is potentially a more cost-effective strategy for addressing nutrient pollution and its impacts.

External Costs Associated with Nutrient Pollution Impacts

Excessive nutrient loading to waterbodies can lead to excessive plant and algal growth, resulting in a range of adverse economic effects. Several studies have documented significant economic losses or increased costs[1] associated with anthropogenic nutrient pollution in the following categories:

- *Tourism and recreation*. Studies from Ohio, Florida, Texas, and Washington (Section III.A.1) provide quantitative estimates of declining restaurant sales, increased lakeside business closures, decreased tourism-associated spending in local areas, and other negative economic impacts of algal blooms. For example, a persistent algal bloom in an Ohio lake caused $37 million to $47 million in lost local tourism revenue over two years.
- *Commercial fishing*. Several studies (Section II.A.2) document the negative impacts of algal blooms to commercial fisheries throughout coastal areas of the United States, including reduced harvests, fishery closures, and increased processing costs associated with elevated shellfish poisoning risks. For example, a harmful algal bloom (HAB) outbreak on the Maine coast prompted shellfish bed closures, leading to losses of $2.5 million in soft shell clam harvests and $460,000 in mussel harvests.
- *Property values*. Elevated nutrient levels, low dissolved oxygen levels, and decreased water clarity can depress the property values of waterfront and nearby homes. Studies in the New England, Mid-Atlantic, Midwest, and Southeast regions (Section III.A.3) have demonstrated these impacts using hedonic analyses[2] that measure the impact of water clarity or direct water quality metrics such as pollutant concentrations on property sales price. In New England, for example, a 1-meter difference in water clarity is associated with property value changes up to $61,000 and in Minnesota, property values changed up to $85,000.
- *Human health*. Algal blooms can cause a variety of adverse health effects (in humans and animals) through direct contact with skin during recreation, consumption through drinking water, or consumption of contaminated shellfish, which can result in neurotoxic shellfish poisoning and other effects. For example, a study from Florida (Section III.A.4) documented increased emergency room visit costs in Sarasota County for respiratory illnesses resulting from algal blooms. During high algal bloom years, these visits can cost the county more than $130,000.
- *Drinking water treatment costs*. Excess nutrients in source water for drinking water treatment plants can result in increased costs associated with treatments for health risks and foul taste and odor. For example, a study in Ohio (Section III.B.1) documents expenditures of more than $13 million in two years to treat drinking water from a lake affected by algal blooms.
- *Mitigation*. Nutrients that enter waterbodies can accumulate in bottom sediments, acting as sources of loadings to the water column. In-lake mitigation measures such as aeration, alum treatments, biomanipulation, dredging, herbicide treatments, and hypolimnetic withdrawals may be necessary to address the resultant algal blooms. Several studies (Section III.B.2) have documented these measures and the costs associated with them for individual waterbodies. These costs range from $11,000 for a single year of barley straw treatment to more than $28

[1] Unless otherwise indicated, all dollar values are updated to 2012$ using appropriate indices.

[2] Hedonic means of or relating to utility. In a hedonic econometric model, the independent variables relate to quality, such as the quality of a home one might buy.

million in capital and $1.4 million in annual operations and maintenance for a long-term dredging and alum treatment plan.

- *Restoration*. There are substantial costs associated with restoring impaired waterbodies, such as developing total maximum daily loads (TMDLs), watershed plans, and nutrient trading and offset programs (Section III.B.3). For example, there are several trading and offset programs that have been developed specifically to assist in nutrient reductions. One developed for the Great Miami River Watershed in Ohio for nitrogen and phosphorus had estimated costs of more than $2.4 million across 3 years.

Costs Associated with Nutrient Pollution Control

Addressing nutrient pollution entails the deployment of nutrient pollution controls for point and/or nonpoint sources. Data were extracted and compiled from recent studies related to the costs for treatment systems and other controls that have been employed by point and nonpoint sources to reduce the discharge of nutrients to surface waters. Highlights of the data and information collected are provided here.

- *Municipal Wastewater Treatment Plants*. The capital and operation and maintenance (O&M) costs for nitrogen and phosphorus were found to vary based on numerous factors, including the types of treatment technologies and controls used and the scale of the plant (Section IV.A.1). Many of the best performing plants (in terms of final effluent concentrations achieved) utilized some form of biological nutrient removal (BNR) process paired with filtration. Unit costs for these types of systems were generally lower as the size of the plant increased. Most treatment technologies designed for nitrogen removal were reported to achieve effluent concentrations between 3 mg/L and 8 mg/L, and most treatment schemes for phosphorus removal (which typically involved one or more treatment processes) were reported to achieve effluent concentrations of 1 mg/L or less.

- *Decentralized Wastewater Treatment Systems*. Limited data were available to assess costs associated with nutrient control in small communities, with all available data originating from three sources (Section IV.A.2). Data regarding phosphorus removal were extremely limited, and associated costs could not be reliably estimated.

- *Industrial Wastewater Treatment*. Data on nutrient control in industrial wastes were largely limited to one source on meat and poultry products processors and reported on the nutrient control performance of three treatment strategies (Section IV.A.3). In general, an enhanced aeration treatment process produced the most reliably low nitrogen effluent concentrations, while chemical phosphorus removal produced the most reliably low phosphorus effluent concentrations.

- *Urban and Residential Runoff*. Costs associated with the control of nutrients in stormwater runoff from urban and residential areas were reported for a range of structural and non-structural best management practices. For example, infiltration basins were found to have a phosphorus removal efficiency of 65% with costs ranging from $819/m^3 to $1,768/m^3, and programs to identify and correct illicit discharges into storm sewer systems had costs (based on 20-year present worth) as low as $8.82 per pound of nitrogen removed and $35 per pound of phosphorus removed.

Table of Contents

Appendices

List of Tables

List of Figures

I. Introduction

This report presents the findings from a U.S. Environmental Protection Agency (EPA) effort to compile current information regarding costs associated with nutrient pollution. Such costs may be of two broad types. Some costs are associated with reducing nutrient pollution at its sources. Other costs are associated with the impacts of nutrient pollution in the environment. This latter category of costs is referred to as "external costs" or "externalities," because they are "external" to the owners of the farms, businesses, or facilities that generate them. The EPA is providing this work to help states, tribes, and other stakeholders consider cost data from various sources, geographic locations, scales, and waterbody types in the development of policies and tools to reduce nutrient pollution.

I.A. What is nutrient pollution and why is it a concern?

In this report, the term "nutrient" refers to nitrogen and phosphorus, two essential elements for the growth and proliferation of flora (e.g., plants and algae), which in turn support various grazers and consumers across the food web. In aquatic environments, nitrogen and phosphorus are available in organic and inorganic forms and in dissolved and particulate forms. Nitrogen and phosphorus can come from natural sources through physical, chemical, geological and biological processes, but they can also come from anthropogenic sources like agriculture (e.g., animal manure, synthetic fertilizer application), municipal and industrial wastewater discharges (e.g., wastewater treatment plants, septic systems), stormwater runoff, and fossil fuel combustion. This report focuses solely on anthropogenic sources of nutrients to surface waters.

While some amount of nutrients is needed to support aquatic communities, excess nitrogen and phosphorus (or "nutrient pollution") can cause an overstimulation and overabundance of plant and algal growth that can lead to a number of deleterious environmental, human health and economic impacts (Dodds et al., 2009; Weaver, 2010). For example, nutrient pollution can lead to harmful algal blooms (HABs) that produce toxins that can sicken people and pets, contaminate food and drinking water sources, kill fish and other fauna, and disrupt the balance of natural ecosystems. As it decays, the large amount of organic material generated by the bloom can cause oxygen concentrations in the water to decline below levels needed to support many aquatic organisms, leading to areas called "dead zones" in lakes, estuaries and coastal waters. HABs can also raise the cost of drinking water treatment, depress property values, close beaches and fishing areas, and negatively affect the health and livelihood of many Americans.

In the summer of 2014, for example, a massive bloom of cyanobacteria (or blue-green algae) in Lake Erie resulted in the closure of drinking water facilities that served 500,000 people in Toledo, OH (see The Blade, August 2, 2014; New York Times, August 8, 2014). The shutdown garnered national attention and brought focus to the problem of algal blooms around the country.

According to the EPA's Fiscal Year 2014 *National Water Program Guidance*, "nitrogen and phosphorus pollution is one of the most serious and pervasive water quality problems" in the United States (U.S. EPA, 2013). The finding that nutrient pollution is the leading cause of use impairment in U.S. waters is supported by data from states' water quality assessment reports, National Aquatic Resources Surveys, and associated reports to Congress (see the EPA's Nitrogen and Phosphorus Pollution Data Access Tool for these reports and surveys at http://www2.epa.gov/nutrient-policy-data/nitrogen-and-phosphorus-pollution-data-access-tool#other).

An Urgent Call to Action—Report of the State-EPA Nutrient Innovations Task Group (U.S. EPA, 2009) acknowledged that the degradation of surface waters associated with nutrient pollution has been extensively studied and documented. The report concluded that the rate and impact of nutrient pollution will continue to accelerate when coupled with continued population growth. Several scientific studies indicate that global climate change, mainly warming conditions, is expected to exacerbate the nutrient pollution problem (Paerl and Huisman, 2009; O'Neil et al., 2012; Paerl and Paul, 2012).

Whether in groundwater, lakes or reservoirs, rivers or streams, estuaries or marine coastal waters, the impacts from nutrient pollution continue to increase year after year. The *Urgent Call to Action* report (U.S. EPA, 2009) noted that current actions to control nutrients have largely been inadequate. Reducing nutrient pollution continues to be a high priority for the EPA and its federal, state and local partners.

I.B. What can state, tribal, and local governments do?

The EPA has released several documents in recent years about actions that state, tribal, and local governments can take to reduce nutrient pollution. Each of these documents encourages states and tribes to make strong progress to achieve near-term reductions in nutrient loadings as they work to develop numeric nutrient criteria in water quality standards to guide longer term reductions.

An Urgent Call to Action (U.S. EPA, 2009) recommended that a common framework of responsibility and accountability for all point and nonpoint pollution sources is central to ensuring balanced and equitable upstream and downstream environmental protection. The report concluded that available tools to reduce nutrient loadings are underutilized and poorly coordinated. It also called for broader reliance on incentives, trading, and corporate stewardship.

In the "Recommended Elements of a State Framework for Managing Nitrogen and Phosphorus Pollution," [3] the EPA described the eight elements a state should include in a Nutrient Pollution Reduction Strategy. States should (1) identify the watersheds that contribute the largest loadings of nutrients, (2) set watershed load reduction goals, (3) ensure effectiveness of point source permits in priority sub-watersheds, (4) develop plans for effective practices in agricultural areas, (5) identify reductions in storm water and septic systems, (6) develop accountability and verification measures, (7) have public reporting on implementation and load reductions, and (8) develop a schedule for numeric nutrient criteria development. Overall, these approaches seek to make meaningful and measurable near-term reductions in nutrient pollution while continuing to work on longer-term effort such as numeric criteria development and implementation.

In terms of the activities identified for controlling nutrient pollution, the EPA's *National Water Program Guidance* (U.S. EPA, 2013) states:

> *EPA encourages states to begin work immediately setting priorities on a watershed or statewide basis, establishing nutrient reduction targets, and adopting numeric nutrient criteria for at least one class of waterbodies by no later than 2016.*

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[3] The framework was provided as an attachment to the EPA Memorandum from Nancy K. Stoner, Acting Assistant Administrator, Office of Water, to Regional Administrators, Regions 1-10. March 16, 2011. "Working in Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions."

I.C. How can this report help?

Cost is a major factor in the management and control of nutrient pollution. The *Urgent Call to Action* report (U.S. EPA, 2009) noted that cost data associated with nutrient-related pollution impacts were limited. This report aims to address that deficiency. Stakeholders and partners at the federal, state, tribal and local levels need a better understanding of the cost implications of nutrient pollution, including both the external costs borne by local economies and the costs that would be incurred to curtail nutrient pollution. In many cases, these considerations can drive stakeholders' decisions to pursue nutrient controls, including the development and implementation of nutrient water quality standards.

This report provides users with a compilation of current economic information and references to assist stakeholders – state and tribal managers, local governments, legislators, the regulated community, and the general public – in understanding and evaluating the costs of removing nutrients at their source or preventing the manifestation of nutrient pollution (e.g., harmful algal blooms (HABs)), relative to the costs associated with no or delayed action (e.g., HAB impacts). The information in this document may help interested parties evaluate other cost estimates.

Controlling nutrient pollution is costly, but the external costs of not acting or delaying action can also be significant. As this report shows, the adverse effects of nutrient pollution cause economic losses across many sectors and scales (i.e., local to national) and impose costs to protect human health and aquatic life. For example, a number of published studies pointed to substantial impacts in sectors such as recreation, tourism, aquaculture, fisheries, real estate, and public/private water supply due to HABs. In addition, the report found significant costs for waterbody mitigation (e.g., alum addition) and restoration of nutrient-polluted waterbodies.

The assessment of the actual costs associated with the impacts of nutrient pollution, as well as the costs for controlling the pollution, are site specific and depend on numerous factors, such as the characteristics of the waterbody/watershed (e.g., geographic location, type of waterbody, level of impairment, nutrient sources) and the form of the nutrient criteria (narrative[4] vs. numeric) and stringency of water quality criteria and standards. It can also often be difficult to fully complete the chain of reasoning required to link nutrient pollution to an accurate estimate of external costs. For example, nutrient pollution has been shown to be related to the occurrence of HABs (see, e.g., Heisler, et al. 2008), and a number of studies estimate the economic consequences of HABs. Other factors also affect the occurrence of HABs, however, and it can be difficult to distinguish their effects from those of nutrients. Thus, it is often difficult or impossible to say *how much more* likely an HAB is because of nutrient pollution. This information is needed in order to estimate external costs, however. Moreover, accurate calculation of external costs often requires observing some careful distinctions. If a decline in local water quality were to lead to a seaside restaurant closing, the cost of that closure would not be measured by the lost revenues of the restaurant, or even its lost profits, but rather, by the *difference* between the profits the restaurant could make when the water was clean and the profits that would be earned by whatever other business might subsequently occupy the site.

The control costs data and information compiled for this report are instructive in that they provide relative order of magnitude estimates appropriate for screening or feasibility analyses, and can be used to add perspective to the costs of not implementing controls. Readers can take the information

[4] Narrative criteria are descriptive, non-numeric expressions for the desired condition of a given parameter.

in this report to inform and initiate the process at the state, tribal, and local level to develop policies and tools to reduce nutrient pollution.

I.D. What is the scope of this report?

This report compiles data and information from the technical literature related to the economic impacts of nutrient pollution (i.e., the external costs associated with not taking or delaying action to reduce nutrients in receiving waters, resulting in negative impacts such as economic losses and increased costs) and the costs associated with the control of nutrient pollution (i.e., point and nonpoint source controls, restoration, and mitigation). Where data were available, this report includes information on nutrient reductions expected from various control strategies to provide additional perspective on the range of performance relative to the cost of implementing the strategy.

This compilation focuses on data from a range of sources including published, peer-reviewed journals, government-funded research and reports, academic studies and other data sources that met data quality objectives and procedures set forth in this report (see Methods section). The main body of this report includes results from studies that met the screening criteria specified in the Quality Assurance Project Plan (QAPP) for this project. In accordance with the EPA's policies, the QAPP ensured the quality and reproducibility of the data collected and subsequently used for this report. The QAPP established the project approach for data assessment and acceptance. The screening criteria were established to identify relevant (e.g., quantitative cost data were provided) recent studies from a variety of sources.

The main body of this report does not include results from anecdotal reports that mention impact costs due to nutrient pollution (e.g., media reports, newspaper and magazine articles) that could not be traced or independently verified. However, Appendix A contains those for readers interested in the full gamut of reported costs.

Similarly, this report does not include results of cost-benefit studies and other reports of methodologies for developing cost estimates to support state-specific criteria derivation (e.g., the costs to attain proposed water quality criteria and associated effluent limitations) in the body of the report because these analyses were conducted with specific assumptions and conditions that are different from the purpose of this study. This report does, however, consider and use the source data from those cost-benefit studies. Appendices B and C contain those references.

A companion spreadsheet to this report contains the compiled cost data and information.

I.E. What doesn't this report include?

This report focuses solely on impacts of anthropogenic sources of nutrients on surface waters such as streams, lakes, estuaries, and coastal waters. Due to resource limitations, this report does not include nutrient-related impacts on wetlands and groundwater. Likewise, this report does not include nutrients from air deposition, overflows of combined sewer systems, or groundwater sources. While the EPA recognizes that there are cost data associated with the control of nitrogen from these sources, as well as external costs associated with their impacts, this study excluded them at this time to limit the scope of the review and meet resource limitations.

Although agricultural activities (e.g., crops and agricultural fields, livestock management) can be a significant non-point source of anthropogenic nitrogen and phosphorus into surface waters, we did not include information in this report on the costs to control nutrients (e.g., from best management practices) because of the significant breadth and depth of approaches. We intend to focus on those approaches and costs in a supplement or addendum to this report.

While this report provides data relevant to the external costs and control costs for nutrient pollution to inform decision making, this report does not compare the results in these two categories. It would not be appropriate to do so because the various studies vary in their analyses, methodologies, starting conditions and initial assumptions, making it difficult to compare them directly. In addition, not all costs are relevant to every localized nutrient analysis.

In addition, the reader should not use the results in this report to claim that certain investments to upgrade a given facility or implement a best management practice (BMP) will eliminate the exact external costs reported here associated with nutrient pollution that would apply in a site-specific area. This report provides baseline cost information for each category that would not necessarily be valid to extrapolate to a specific circumstance.

This report does not attempt to calculate the economic benefits[5] of particular levels of reduction of nutrient pollution. For interested readers, Appendix B describes some state-level cost and benefit studies. Additional references for benefit studies are in Appendix D.

I.F. How is the rest of this report organized?

The remainder of this report is organized as follows:

- Section II highlights the methods used to collect and compile cost information for this project. This discussion is organized around a graphical representation of how nutrients affect the ecology of a waterbody and how nutrient pollution changes that ecology and affects various uses. The conceptual diagrams served as a guide and framework for this project.
- Section III summarizes the costs attributable to impacts of nutrient pollution and controlling its effects.
- Section IV summarizes the data and information related to the costs to control the sources of nutrients.
- Section V provides references.
- Appendix A includes additional evidence of the costs of nutrient pollution.
- Appendix B summarizes cost-benefit analyses that have been performed in support of various nutrient rulemaking efforts.
- Appendix C provides supplemental anecdotal point source control costs.
- Appendix D lists additional references for benefit studies.
- Appendix E provides a compilation of the abbreviations and acronyms used in Section IV related to treatment technology abbreviations and acronyms.

[5] Market values do not represent the total economic value that may be affected by nutrient pollution. See Chapter 1 of Restore America's Estuaries' "The Economic and Market Value of Coasts and Estuaries: What's at Stake?" (Pendleton, 2008) for an easy-to-understand discussion of how economic activities that generate few revenues still generate significant economic value (e.g., bird watching and beach going). This total economic value is the subject of benefits analyses.

- Appendix F provides a users' guide for using the project spreadsheet that contains all the data compiled for the project (described in Section II.F).

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II. METHODS

This section describes the methods used to compile the costs related to the economic impacts of nutrient pollution. It also presents information on the cost of nutrient source control and remediation.

II.A. Model of Nutrient Pollution Pathways

Contributions to nutrient pollution originate from various sources, resulting in many potentially adverse effects to uses of surface waters (see Box 1). Examples of uses that are impacted by nutrient pollution include municipal and private water supply, recreation, aquatic life, agricultural and industrial water supply, and wildlife habitat. We present the following discussion to delineate the scope of this document in terms of analyzing nutrient-related costs, and to define the categories used as the basis for the literature review for nutrient control costs.

We portray through diagrams the pathways where nutrients entering waterbodies and watersheds may lead to potential economic losses and impacts to uses. This report uses a conceptual diagram by Weaver (2010) that relates nutrient enrichment to impacts on human health and aquatic life in areas such as commercial and recreational fishing, tourism, aquaculture, swimming, species diversity, organism condition, ecosystem function, and nursery areas. For example, Weaver (2010) illustrates the pathway from nutrient pollution to algal dominance changes, decreased light availability, and increased organic decomposition. These primary responses can then result in secondary responses that include presence of harmful algae, loss of submerged aquatic vegetation, and low dissolved oxygen levels. Dodds et al. (2009) also identify effects of increased nutrients that could influence the value of freshwater ecosystem goods and services.

Box 1. Uses Potentially Impacted by Nutrient Pollution

States and tribes identify the specific uses of waters within their jurisdictions. In general, those uses include:

- Municipal and private water supply
- Recreation (swimming, boating)
- Aquatic life, including cold water and warm water fisheries
- Agricultural and industrial water supply
- Navigation

Figures II-1 and II-2 show modified versions of Weaver's (2010) conceptual diagram for lakes and flowing water (Figure II-1) and for estuarine and coastal waters (Figure II-2). There are some slight differences between the two models, such as the list of potentially impacted sectors. There are also no examples of short-term, direct waterbody mitigation approaches in estuarine and coastal waters. As detailed in the figures, anthropogenic sources of nutrient pollution that may need to be site-specifically controlled to reduce negative impacts include:

- Municipal and industrial wastewater treatment plants
- Agricultural sources
- Urban stormwater
- Onsite septic systems.

Figures II-1 and II-2 thus illustrate the pathways from potential sources of nutrient pollution to the potential economic losses and increased costs that may result from nutrient impairment in fresh and estuarine waters:

- Commercial fisheries losses
- Recreation and tourism losses
- Reductions in property values
- Increased costs to treat municipal or private drinking water
- Short-term, waterbody mitigation costs (e.g., dredging, alum treatments, aeration, destratification of the water column)
- Costs of regulatory actions triggered by impaired water quality (e.g., Safe Drinking Water Act compliance, total maximum daily loads (TMDLs), watershed plans).

II.B. Literature Review Search Categories

As described in the previous section, the modified versions of Weaver's diagram portray the pathways where nutrients may lead to economic losses and negative impacts to uses. From these diagrams, Table II-1 presents the categories of nutrient sources used as the basis for the extensive literature search and review for nutrient control costs.

Table II-1. Categories Used for Collecting Nutrient Control Cost Data

Cost Category	Subcategory
Point source	Municipal treatment
	Industrial treatment
	Onsite septic systems
Non-point source	Urban runoff
	Commercial forestry

Table II-2 presents the categories used as the search criteria for the literature review for economic impact costs associated with nutrient pollution.

Table II-2. Sectors and Types of Impacts Used for Economic Cost Data

Sector	Economic Impact
Tourism-related Industries	Lost revenue
Commercial Fisheries	Lost revenue
Households	Decreased property value
	Cost of illness
Other Industry	Increased operational costs
Municipalities	Increased cost of drinking water treatment

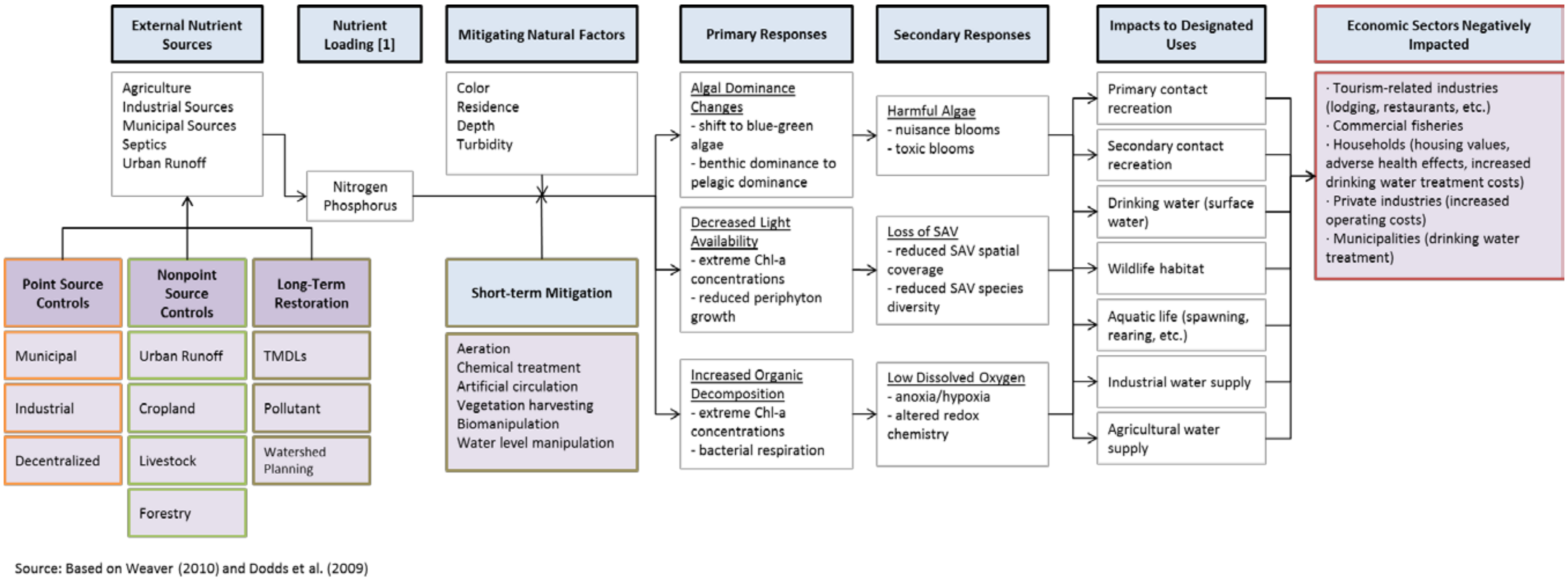

Figure II-1. Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.

Source: Based on Weaver (2010); Dodds et al. (2009).

[1] Loads to surface waters. Infiltration throughout the watershed may also contaminate groundwater used for drinking water source water.

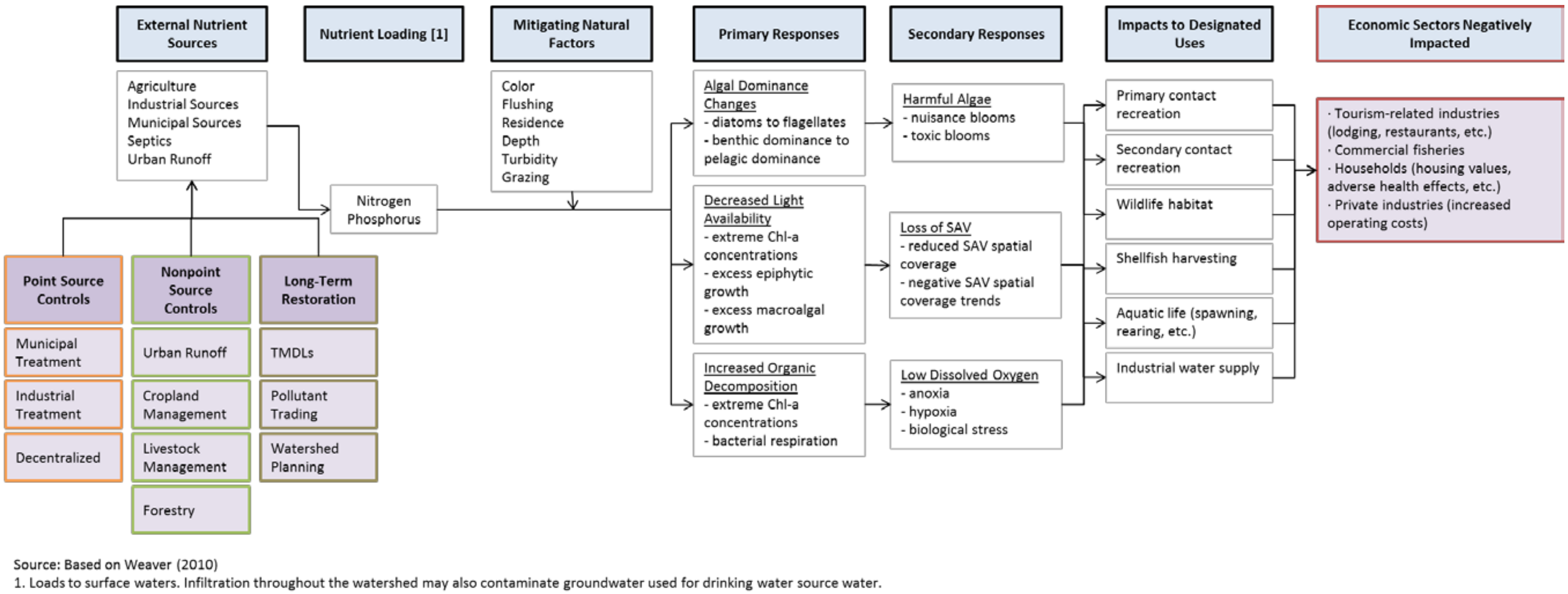

Figure II-2. Relationship of nutrient discharges to economic impacts associated with water quality in estuaries and coastal waters.

Source: Based on Weaver (2010).
[1] Loads to surface waters. Infiltration throughout the watershed may also contaminate groundwater used for drinking water source water.

After a waterbody becomes negatively impacted (or "impaired" from a regulatory standpoint) due to nutrient pollution, costs may also be incurred from actions taken to mitigate the impacts directly in a waterbody. We report further costs in restoration efforts from regulatory and non-regulatory actions to address the impairment of a waterbody. Table II-3 presents the categories used as the basis for the literature review for collecting cost data related to direct waterbody mitigation and restoration costs.

Table II-3. Categories Used for Collecting Cost Data Related to Mitigation and Restoration Costs

Cost Category	Subcategory
Mitigation	Lakes/reservoirs
	Rivers/streams
	Coasts/estuaries
Restoration	Total maximum daily loads
	Pollutant trading
	Watershed planning

II.C. Literature Review Screening Criteria

We used screening criteria to focus the abundant data and information that exist in the technical literature related to the impacts of, and costs to control, nutrient pollution. The following describes the specific criteria used to select the literature (e.g., studies, reports, papers) from which cost data were considered for this project:

- Quantitative cost data were provided.
- The cost data were developed based on the control of, or impacts from, actual or existing occurrences of nutrient pollution.
- The cost data were developed from original research or methods to avoid secondary interpretation by authors and researchers.
- The reported cost data were directly related to the impacts from, or controls for, nutrient and nutrient pollution. Cost data were also included from studies and reports related to dissolved oxygen or harmful algal bloom (HAB) impacts that were or may be attributable to nutrients.
- In general, cost data prior to the year 2000 were not considered, especially for nutrient controls. Post-2000 cost data better reflect recent technologies (i.e., state-of-the-art) as well as improved control performance. For costs of economic impacts and mitigation and restoration, older data were considered if the data were directly attributable to nutrient pollution and more recent data were not available. The majority of the literature review ended with publications in 2012. A few publications that came to our attention after 2012 were considered, if time allowed for a thorough review.
- As a means to assure data quality and reproducibility, studies, reports, or papers containing cost data were selected only from published, peer-reviewed literature or from documents prepared for use by the U.S. Government or state governments with similar standards for quality and associated data quality objectives.

II.D. Literature Sources

Based on the search categories and screening criteria in Sections II.B and II.C, we reviewed the literature to identify possible sources of cost data and information relevant to impacts from nutrient pollution. We used several resources as the primary source of studies, reports, and papers:

- Existing studies related to nutrient pollution impacts and control costs performed and underway by the EPA Office of Water and other EPA offices. Data already analyzed as part of EPA regulatory impact analyses met EPA-approved quality data objectives and procedures. For example, the studies that formed the basis for biological nutrient removal treatment technology unit costs originally developed by the EPA's Office of Wastewater Management were used for EPA's economic analysis of numeric nutrient criteria for Florida waters because they provide appropriate and relevant estimates for this project.
- A general Internet search for cost data was conducted using websites such as Google Scholar. In addition, website searches were performed of journals by relevant industry associations (e.g., Water Environment Research Foundation). Key search terms included, but were not limited to, those indicated in Section II.B.
- The subscription-based, online information service ProQuest Dialog.
- Studies, reports, and papers provided by EPA regional offices and state water quality protection representatives.

II.E. Data Quality Review

For this project, we assessed the quality of secondary data and information collected from the literature review considering the five assessment factors recommended by the EPA Science Policy Council's *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (U.S. EPA 2003). The five factors excerpted directly from the EPA Science Policy Council's guidance are:

- **Soundness:** The extent to which the scientific and technical procedures, measures, methods, or models employed to generate the information is reasonable for, and consistent with, the intended application.
- **Applicability and Utility:** The extent to which the information is relevant for the agency's intended use.
- **Clarity and Completeness:** The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations, and analyses employed to generate the information are documented.
- **Uncertainty and Variability:** The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods, or models are evaluated and characterized.
- **Evaluation and Review:** The extent of independent verification, validation, and peer review of the information or of the procedures, measures, methods, or models.

We assessed each of the studies, reports, and papers collected as part of the literature review for quality as described in the guidance. If a source met the data quality requirements contained in the QAPP prepared for this project, we extracted the cost data from the source for use in this report. We updated all dollar values from the original reported results to 2012 dollars (2012$) using the Consumer Price Index.

II.F. Project Spreadsheet/Database

We compiled the detailed data and information collected and extracted for this project in a project spreadsheet that can be accessed through the EPA's nutrient pollution policy and data website at http://www2.epa.gov/nutrient-policy-data/reports-and-research. Appendix F provides a brief users' guide to assist interested parties in navigating the spreadsheet and on the use of the detailed data.

We retained relevant or recently published material that could be considered for this report or for any future updates elsewhere. Likewise, we also collected and retained information that was excluded from the scope of this work as outlined in Section I.C (e.g., nutrient impacts in wetlands and groundwater) for any future expansion of this report. Researchers and other parties may submit information that we may have missed or new information that was not available at the time of review to the project lead, Mario Sengco (sengco.mario@epa.gov), or send the information to the following address: U.S. Environmental Protection Agency, OW/OST/SHPD, 1200 Pennsylvania Avenue NW, MC 4305T, Washington D.C. 20460. If those submissions pass the screening and quality control requirements, we will add them to any updates of the database of information and the report.

II.G. References Cited

Dodds, W. K., W.W. Bouska, J. L. Eitzmann, T.J. Pilger, K.L. Pitts, A.J. Riley, J.T. Schloesser, and D.J. Thornbrugh. 2009. Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages. American Chemical Society: Environmental Science and Technology, Policy Analysis, Vol. 43, No. 1: 12-19.

U.S. Environmental Protection Agency. 2003. A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information. (EPA 100/B-03/001).

Weaver, K. 2010. "Estuary and Coastal Waters Numeric Nutrient Criteria: Workshop Introduction." Estuary Numeric Nutrient Criteria Public Meeting for Portions of the Florida Coast from Dixie County to Pasco County.

III. Cost of Nutrient Pollution

This section summarizes the results of a literature search of recent studies documenting the adverse economic impacts of anthropogenic (human-caused) nutrient pollution and costs associated with programs to reduce these impacts. All dollar values were updated from the original reported results to 2012 dollars (2012$) using the Consumer Price Index.[6] Excessive nutrient loading to waterbodies in the United States can lead to over-enrichment and algal blooms, resulting in a myriad of adverse economic effects in sectors that include commercial fisheries, real estate, and tourism and recreation, and an increase in health care and drinking water treatment costs. Additionally, mitigation measures that local governments use to reduce the effects in the water (such as algal blooms) can cost millions of dollars for a single year of treatment.

A number of studies reported estimates of economic losses and increased costs that have resulted from the processes described in Section II. To provide some differentiation regarding the available information, the studies were screened using certain criteria for reliability (see Box 2). The studies summarized here do not encompass all impacts of nutrient pollution; instead, they represent a subset of what has occurred or is available in the literature between the years 2000 and 2012, including some relevant information before 2000 where more recent information is insufficient. The literature does not provide complete information on many such impacts throughout the United States since there is not adequate documentation of all impacts. Anecdotal and other information on the external costs of nutrient pollution are summarized in Section III.A.5 and Section III.B.4. Appendix A provides further details.

Box 2. Screening Criteria for Studies of the Economic Impacts of Nutrient Pollution

- Quantitative estimates of adverse economic impacts from nutrient pollution
- Primary studies
- Specific to nutrients, dissolved oxygen, or algal blooms
- Estimates related to actual or existing occurrences of nutrient pollution (e.g., excludes estimates related to projected nutrient pollution, such as a proposed nutrient criteria rule)
- Peer-reviewed, government-funded, academic, or other quality data sources.

This literature review relates to the economic losses, or external costs, associated with nutrient pollution. For an overview of selected cost-benefit analyses of specific nutrient-reducing regulatory programs, see Appendix B.

III.A. Economic Losses

The studies summarized here document the economic losses arising from anthropogenic nutrient pollution. However, some of the losses documented in this section are the result of “red tides,” a type of harmful algal bloom (HAB) that affects coastal areas. Red tides can occur naturally; as such, the impacts associated with red tide events may be partially or fully attributable to natural drivers rather than to anthropogenic nutrient loading. In some cases, however, the impacts associated with harmful algal blooms are likely attributable to nutrient runoff from human sources (e.g., Gulf of Mexico hypoxic zone) (see National Academy of Science, 2009). Evidence has shown that red tide events have been increasingly frequent and severe in recent decades, with anthropogenic nutrient

[6] For drinking water treatment costs, the Construction Cost Index was used to update estimates to 2012$.

pollution providing significant quantities of nutrients that drive blooms, especially near shore (Heisler et al. 2008; Hochmuth et al. 2011).

The areas of economic impact are divided into tourism and recreation, commercial fishing, property values (separated into specific geographic areas of the country), and human health.

III.A.1. Tourism and Recreation

Harmful algal blooms were the primary examples of nutrient-related impacts found in the literature review. These blooms can lead to beach closures, health advisories, aesthetic degradation, and other impacts that are damaging to tourism industries surrounding affected waterbodies. Table III-1 summarizes documented impacts of HABs to local tourism and recreation industries from examples in Ohio, Texas, Washington, and Florida.

Table III-1. Examples of Estimated Tourism and Recreation Economic Losses due to HABs

Study	State	Waters	Economic Losses (2012$)[1]
Davenport and Drake (2011); Davenport et al. (2010)	OH	Grand Lake St. Marys	• $37–$47 million estimated loss in tourism revenues in 2009 and 2010. • 5 lakeside business closures. • $632,000 loss due to regatta cancellation. $263,000 decline in park revenues.
Oh and Ditton (2005)	TX	Possum Kingdom Lake	• 5% (2001) and 1.9% (2003) decrease in total economic output. • 57% (2001) and 19.6% (2003) decline in state park visitation.
Evans and Jones (2001)	TX	Galveston Bay	• In 2000, 85 shellfish bed closure days resulted in $13.2– $15.3 million direct impact and $21.3–$24.6 million total impact.
Larkin and Adams (2007)	FL	Ft Walton Beach and Destin areas	• $4.2 million and $5.6 million in reduced restaurant and lodging revenues, respectively, during HAB events.
Morgan et al. (2009)	FL	Southwest coast	• Reduced daily restaurant sales of $1,202 to $4,390 (13.7%–15.3%) during HAB events.
Dyson and Huppert (2010)	WA	Beaches in Grays Harbor and Pacific Counties	• Typical closure (2–5 days) results in $2.23 million in lost labor income and $6.13 million in sales impacts due to decreased visitation.

HABs = harmful algal blooms

[1] *All economic losses updated to 2012$ using the Consumer Price Index.*

For example, Grand Lake St. Marys is the largest inland lake in Ohio, covering 13,000 acres. It is a shallow lake that supplies water for the City of Celina and the Village of St. Marys. As a result of agricultural runoff, failing home sewage systems, internal nutrient loading, and other runoff, the lake is hyper-eutrophic, experiencing large algal blooms and frequent fish kills (Davenport and Drake, 2011). In 2009, sampling showed dangerously high levels of toxins produced by blue-green algae, and the Ohio EPA subsequently posted signs advising people to avoid contact with the water. Algal blooms in 2010 caused scum and fish kills throughout the lake, as well as 23 reported cases of human illnesses and dog deaths.

These advisories and blooms have had profound impacts on the area's tourism industry, which had previously accounted for $158 million in annual economic activity (Davenport and Drake, 2011; Davenport et al. 2010). According to Davenport and Drake (2011), small businesses around the lake have lost $37 million to $47 million in revenues, and several local marinas and boat dealers have gone out of business. Additionally, a nearby state park has lost approximately $260,000 in revenues (Davenport and Drake, 2011; Davenport et al., 2010). A regatta was also canceled as a result of the algal blooms, resulting in a loss of $632,000 (Davenport et al., 2010).

Another example of the adverse economic impacts of HABs on lake tourism economies is the golden algae (*Prymnesium parvum*) outbreaks in Possum Kingdom Lake in Texas in 2001 and 2003. These events had significant adverse effects on the industries supporting recreational fishing in the lake (Oh and Ditton, 2005). During the golden algae outbreak of 2001, more than 200,000 fish were killed, including many prized game species. In 2003, another golden algae outbreak caused a fish kill of more than 1.4 million fish. Oh and Ditton (2005) found that state park visitor numbers during the two outbreak years declined 57% and 19.6%, respectively.

Oh and Ditton (2005) estimated the economic impacts of associated decreases in recreational expenditures in three counties surrounding the lake using angler surveys together with economic modeling software (IMPLAN [7]). Their estimates showed a decrease of 5% and 1.9% in total economic output in five tourism sectors[8] in 2001 and 2003, respectively. The authors note that there are also likely to be longer-term adverse impacts associated with golden algae outbreaks since anglers perceive diminished fishing opportunities in the area as a result of publicized events.

HABs can also have adverse effects in coastal areas. For example, authorities in Washington regularly sample shellfish in coastal razor clam fisheries for toxins produced by HABs. These algal toxins cause adverse health effects, including amnesic or paralytic shellfish poisoning (Dyson and Huppert 2010). When the toxins exceed critical levels, recreational razor clam fisheries close, causing local economic impacts. Dyson and Huppert (2010) surveyed visitors to four razor clam fishing beaches in two counties in coastal Washington to collect data on expenditure and visitation patterns during fishery openings and closures. They used these data in an economic input-output model,[9] estimating that a typical closure (2 to 5 days) results in lost labor income of $2.23 million and a total spending impact of $6.13 million at the four beaches.

In other coastal areas, red tides[10] can discolor water, cause fish kills, contaminate shellfish, and cause respiratory distress in humans and other mammals (Evans and Jones 2001). These effects can result in significant economic impacts, including lost tourism and recreation opportunities. For example, in 2000 a red tide event in Galveston Bay had a profound economic impact on Galveston County in Texas. Evans and Jones (2001) used IMPLAN to estimate that this event, which resulted in 85 days

[7] IMPLAN is a regional economic impact model that can be used to forecast the direct, indirect, and induced economic impacts of programs, policies, or events.
[8] Includes food and beverage stores; food services and drinking places; general stores not otherwise classified; hotels and motels; and other amusement-gambling and recreation businesses.
[9] Dyson and Huppert (2010) used a custom input-output model (a simple linear representation of the economy) designed for the two counties. The input for this model is expenditures by razor clammers, and the outputs are net sales impact, labor employment, and labor income.
[10] As noted above, red tide events can be natural phenomena; as such the impacts of red tide documented in these studies may be at least partially attributable to natural drivers rather than anthropogenic nutrient loading. However, as noted above (see Section III.A), anthropogenic nutrient loading likely contributes to increased frequency and severity of such events.

of shellfish bed closures, had a direct economic impact of $13.2 million to $15.3 million on the county. Including indirect and induced effects, the total impact was $21.3 million to $24.6 million.

Several authors have also used modeling to estimate the tourism and recreation impacts of red tide events in Florida. Larkin and Adams (2007) used a time series model to estimate that restaurant and lodging revenues decline by $4.2 million and $5.6 million, respectively, per month along a 10-mile stretch of shoreline. This represents 29% of revenue in the restaurant sector and 35% in lodging along that 10-mile stretch of shoreline. The authors note that their results capture only month-to-month variation, while the effects of daily fluctuations and other shorter term conditions are not captured.

According to Morgan et al. (2009), the Small Business Association provided 36 businesses in southwest Florida with loans between $5,680 and $96,295 as a result of red tide events between 1996 and 2002. Morgan et al. (2009) used daily sales data from three coastal restaurants in southwest Florida to estimate the impact of red tide events on revenues. They found that individual restaurant sales decreased by $868 to $3,734 (13.7% to 15.3%) each day during red tide events.

As noted by Morgan et al. (2009), Larkin and Adams (2007), and Evans and Jones (2001), the documented tourism impacts arising from algal blooms are localized. In response to outbreaks that impede recreation in one area, visitors may shift their activities to other areas. To the extent that this occurs, the adverse economic impacts associated with HABs represent transfers of economic activity between areas, rather than a true economic loss. As such, the tourism results presented in this section represent only the impacts within the geographic boundaries specified within each study. The impacts described do not necessarily represent true economic losses considering larger geographical areas. On the other hand, there may be a halo effect[11] in which localized events spur avoidance of a much larger area surrounding the affected waterbody, expanding the geographic size and severity of impacts associated with a particular event.

III.A.2. Commercial Fishing

Algal blooms can have extremely damaging impacts to commercial fishing industries in marine coastal areas of the United States due to fish kills, shellfish poisoning, and associated additional processing of affected harvests. In Galveston Bay, Texas, for example, the red tide event that resulted in significant adverse impacts to the tourism and recreation industries (as described in Section III.A.1) also caused economic losses to the commercial oyster industry when shellfish beds were closed for 85 days. According to Evans and Jones (2001), economic losses were valued at $240,000 for the decline in harvests between September and December 2000.

Red tide events also have significant adverse economic impacts elsewhere in the country. Jin et al. (2008) developed estimates of the impacts of a 2005 red tide event that affected commercial shellfisheries in New England. Due to that event, shellfish beds in Massachusetts, Maine, New Hampshire, and 15,000 square miles of federal waters were closed for more than a month during the peak harvest season. As a result, Maine and Massachusetts received federal emergency assistance. In Maine, these closures from April to August in 2005 caused losses of $2.5 million in soft shell clam harvests and $460,000 in harvests of mussels (Jin et al., 2008). Jin et al. (2008) also estimated that impacts to the shellfish industry in Massachusetts may have been as high as $21 million.

[11] The halo effect is a phenomenon in which a localized event causes larger collateral economic impacts, usually in reference to large-scale reductions in seafood consumption in response to local fish kills or health warnings (Anderson et al. 2000; Hoagland et al. 2002).

In Alaska, for example, HABs can cause paralytic shellfish poisoning, which has led to human fatalities and illnesses, and economic losses to shellfish industries since 1990 (RaLonde, 2001). As a result of that poisoning, shellfish harvesters must conduct costly additional testing and processing of their harvests. RaLonde (2001) used harvest revenue data and sales prices of raw and processed clams and crabs to estimate the economic impact of these requirements. In 1998, necessary processing of geoduck clams in Alaska coastal fisheries reduced revenues by $1.1 million. Processing of crabs from the Kodiak/Aleutian crab fishery resulted in losses of $293,000 (RaLonde 2001).

In addition to HABs, nutrient pollution can reduce dissolved oxygen concentrations, which can cause adverse economic impacts to commercial fisheries. In the Patuxent River in Maryland, reductions in dissolved oxygen resulting from nutrient pollution led to a 49% reduction in crab harvests. This reduction caused lost revenues of $304,000 annually (Mistiaen et al., 2003).

Low dissolved oxygen has also caused decreased harvests of commercial fish species in the Neuse River and Pamlico Bay in North Carolina. Huang et al. (2010) estimated the lagged effects of hypoxia on commercial harvests of brown shrimp in these waterbodies. The authors used bioeconomic modeling, assuming that the environmental effects associated with a hypoxia event accumulate over a 60-day period.[12] They found that between 1999 and 2005, the brown shrimp harvest declined by 13.1% (or $44,100) due to hypoxia in the Neuse River. In Pamlico Sound, there was a 13.4% decline worth $1.7 million over the same 7-year period.

Table III-2 summarized losses sustained by commercial fisheries as a result of nutrient loading and algae blooms.

Table III-2. Estimated Commercial Fisheries Losses Due to Reduced Water Quality

Study	State	Waters	Water Quality	Resource Impact	Economic Losses (2012$)[1]
Evans and Jones (2001)	TX	Galveston Bay	HABs	Shellfish bed closures (85 days)	$240,000 (oysters)
Jin et al. (2008)	ME	Maine Coast	HABs	Reduced shellfish harvests due to bed closures	$2,450,000 (soft shell clams); $460,000 (mussels)
Mistiaen et al. (2003)	MD	Patuxent River	Low dissolved oxygen	Reduced crab harvests due to population decline	$304,000 per year
RaLonde (2001)	AK	Coast	HABs	Shellfish poisoning[2]	$1,097,500 (geoduck); $292,900 (crab)
Huang et al. (2010)	NC	Neuse River and Pamlico Bay	Hypoxia	Reduced brown shrimp harvests due to population decline	$44,100 (Neuse River); $1,708,900 (Pamlico Sound)

HABs = harmful algal blooms
[1] All economic losses updated to 2012$ using the Consumer Price Index.
[2] Requires processing of harvest which reduces price compared to raw sales.

[12] The authors also estimated harvest reductions under alternative lagging assumptions (between 30 days and 100 days); these alternative assumptions also resulted in significant effects, with harvests reduced by 9.23%–14.92%.

III.A.3. Property Values

Studies have shown that elevated nutrient levels, low dissolved oxygen levels, and decreased water clarity have resulted in depressed property values of waterfront and nearby homes. Table III-3 summarizes the results of such studies in the New England, Mid-Atlantic, Midwest, and Southeast regions. These studies are hedonic analyses, in which the authors use water quality metrics as variables in house-price regression models to estimate the implicit price of the water quality metric. Most authors use water clarity measures, but some use more direct measures of pollutant concentrations.

Table III-3. Estimated Decreases in Property Values due to Reduced Water Quality

Study	State	Waters	Water Quality	Impact on Home Price (2012$)[1]
Gibbs et al. (2002)	NH	Lakes	Poor water clarity	$1,911 to $16,713 (1% to 6.7%) per 1 meter change in Secchi depth
Poor et al. (2001)	ME	Lakes and ponds	Poor water clarity	$3,917 to $13,535 (3.5% to 8.7%) per 1 meter change in Secchi depth
Boyle et al. (1998)	ME	Lakes	Poor water clarity	$616 to $60,624 (less than 1% to 78%) per 1 meter change in Secchi depth
Michael et al. (2000)	ME	Lakes	Poor water clarity	$1,296 to $15,713 (1.0% to 29.7%) per 1 meter change in Secchi depth
Poor et al. (2007)	MD	Rivers	Elevated dissolved inorganic nitrogen	$22,014 (8.8%) per 1 mg/L increase in dissolved inorganic nitrogen
Kashian and Kasper (2010)	WI	Tainter Lake; Lake Menomin	Algal blooms	$128 to $402 decrease/shoreline foot compared to next comparable lake
Krysel et al. (2003)	MN	Lakes	Poor water clarity	$1,678 to $84,749 per 1 meter change in clarity
Ara et al. (2006)	OH	Lake Erie	Poor water clarity	$25 increase per 1 centimeter increase in clarity; 1.93% change per 1 meter change in clarity
Czajkowski and Bin (2010)	FL	St. Lucie River; St. Lucie Estuary; Indian River Lagoon	Poor water clarity	$6,397 (0.6%) increase in average property value for a 1% increase in clarity
Walsh et al. (2012)	FL	Orange County Lakes	Elevated TN, TP, chlorophyll	17% increase in pollutant causes waterfront properties to decrease: trophic state index = $12,346 (2.1%); TN = $10,307 (1.8%); TP = $7,418 (1.3%); chlorophyll = $4,106 (0.7%)

Secchi depth is a measure of water transparency in lakes and is related to water turbidity.
mg/L = milligrams per liter
TN = total nitrogen
TP = total phosphorus
[1] *All economic impacts updated to 2012$ using the Consumer Price Index.*

New England— Several studies use hedonic analysis to assess the impacts of reduced water clarity on home values in Maine (Boyle et al., 1998; Michael et al. 2000; and Poor et al. 2001) and New Hampshire (Gibbs et al. 2002). Boyle et al. (1998) examined the impacts of water clarity on lakefront home prices (full-time resident homes and vacation homes) in seven groups of lakes across Maine. In four of the markets evaluated, water clarity was a significant variable impacting home prices, with lower clarity resulting in lower home prices. In these markets, a 1 meter increase in water clarity led to a price increase of 1% to 25%. A decrease in water clarity had larger impacts, ranging between less than 1% to greater than 78% for a 1 meter decrease.

Michael et al. (2000) conducted a similar analysis using home sales around 32 lakes in three distinct markets in Maine, but used a wider variety of water quality variables including historical clarity, current clarity, and seasonal variability in clarity. They found that results varied widely depending on residents' perceptions of water quality versus actual water quality metrics, and the timing of the sale versus the water quality measurement. For example, seasonal variation had a much larger impact (8.1% change in house price for a 1 meter change in clarity over the course of a season) than year-to-year variation (1% change in house price for a 1 meter change in clarity from one year to the next). Across all of the variables, the authors found that a 1 meter change in water clarity resulted in a house price change of 1% to 29.7%.

Poor et al. (2001) similarly evaluated the impact of water clarity on lakefront home prices in four markets throughout Maine, comparing the results using objective measures (secchi depth measurements) and subjective measures (survey of lakefront property purchasers) of water clarity. They found that objective measures were a better predictor of sales prices, with a 1 meter change in water clarity resulting in a 3.0% to 6.0% change in house price. Subjective measures of water clarity tended to underestimate clarity (compared to the objective measures), and had a larger impact on house prices (with a 1 meter change resulting in a 3.2% to 8.7% change). However, the subjective measures were worse predictors of sales prices.

Gibbs et al. (2002) conducted a hedonic analysis of lakefront property sales in four markets in New Hampshire, also using water clarity as the water quality variable. They found that a 1 meter change in water clarity resulted in a 0.9% to 6.6% change in property sale price.

Mid-Atlantic— Poor et al. (2007) conducted a hedonic study of waterfront and non-waterfront property sales in the St. Mary's River watershed in Maryland using concentrations of dissolved inorganic nitrogen (DIN) from around the watershed. According to their results, a 1 mg/L change in the dissolved inorganic nitrogen concentration[13] at the nearest monitoring station corresponds to an 8.8% change in home price.

Midwest— Ara et al. (2006) did a study evaluating the impact of water clarity on house prices near 18 Lake Erie beaches in Ohio. At the mean distance to the beach (12.6 kilometers), a 1 meter change in water clarity was associated with a 1.93% change in home value. The authors noted that, as the distance to the beach increased, the impact of clarity on value decreased.

Krysel et al. (2003) did a hedonic study in the Mississippi River headwaters area of Minnesota, using lakefront property sales on 37 lakes, grouped into six distinct markets. They found that water quality had a significant impact on property price in all markets, with a 1-meter change in water clarity resulting in a price change between $1,678 and $84,749 depending on the location/market.[14]

Kashian and Kasper (2010) evaluated two lakes in Wisconsin which both suffer from severe algal blooms, comparing lakefront property sale prices on these lakes to properties on nearby lakes that

[13] Average concentrations across the monitoring stations used were between 0.082 mg/L and 0.956 mg/L; as such, a 1 mg/L would represent a relatively large change in water quality.

[14] Two lakes had higher price effects ($300,571 and $522,018 for a 1-meter change), but these are in a national forest and on an Indian Reservation with considerable publicly owned lakeshore property; as such, additional factors not included in the analysis likely drive the price effects.

are not eutrophic. They found that in the degraded lakes, property values were lower by $128 to $402 per shoreline foot in relation to the next comparable lake.

Southeast— Walsh et al. (2012) assessed the impacts of multiple pollutant concentrations on home values within 1,000 meters of lakes in Orange County, Florida. They estimated the implicit price associated with a 17% change in concentrations of total nitrogen, total phosphorus, chlorophyll, and trophic state index (a composite of the three other nutrient pollutants). For waterfront properties, the impacts ranged from less than 1% of the sales price for chlorophyll to 2.1% for trophic state index. A 17% change in total nitrogen concentrations led to a 1.8% impact on home values; for total phosphorus the impact was 1.3%. The authors note that the impacts were much higher for waterfront homes, with the impacts diminishing with distance to the beach.

Also in Florida, Czajkowski and Bin (2010) used water quality data on the St. Lucie River, St. Lucie Estuary, and Indian River Lagoon to quantify the impact of water quality measures on waterfront home prices in urban coastal housing markets. They found that a 1% increase in water clarity results in the average property price increasing by $6,397 (0.6%), with a range of $2,240 to $10,597 (0.2% to 0.9%).

Variability and Uncertainty— There are several notable sources of variability and uncertainty in all hedonic studies that attempt to discern the impact of water quality on property values. Due to methodological, locational, and situational variability, comparisons across study results and applications of results to other waterbodies can be problematic.

First, the impacts of water clarity are location-dependent. As noted by Gibbs et al. (2002), real estate markets, baseline water clarity, environmental conditions, and population preferences are likely to be highly variable, including within a single region. Gibbs et al. (2002) found that there is little comparability even between Maine and neighboring New Hampshire, with different lake sizes, average home prices, levels of development, and proximity to highways and urban areas.

Poor et al. (2007) noted that their study area was a county adjacent to the Chesapeake Bay, where public opinion polls have shown that local homeowners are knowledgeable about water quality issues and willing to pay for improvements. As such, their results may not be representative of other areas where public education and advocacy for water quality is not as strong. Similarly, Walsh et al. (2012) evaluated the impact of voluntary neighborhood programs where residents pay taxes to control nutrients in particular lakes; in neighborhoods where these programs exist, impacts of water quality changes to home prices are more pronounced.

Baseline water clarity is also an important factor. If water quality is already poor, a 1-meter change can have a larger impact on public perception and sales price than if water quality is high (Michael et al. 2000; Gibbs et al. 2002).[15] Other lake or property characteristics can also influence purchase price, and excluding these characteristics from analyses can result in biased or uncertain results. For example, Gibbs et al. (2002) note that lake clarity has a larger impact on purchase prices when the lake has a larger surface area.

Methodological specifications can also influence the results of hedonic analyses, introducing additional uncertainty. As noted by Michael et al. (2000), authors frequently select water quality variables based on data availability rather than on the best representation of homebuyers' perceptions of water quality. They show that the use of different variables (such as seasonal

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[15] Most authors address this issue by using non-linear functional forms for water quality variables.

variation, current water quality, or historical averages) results in a broad range of implicit prices for water quality. This result indicates that the selection of the water quality variable is important to the validity of the model, but that it is unclear which measure is the best indicator of water quality impacts.

Another source of variability across studies is the use of disparate variables to measure water quality. For example, some studies attempt to isolate the impact of water clarity alone, while others use interaction variables which capture the impacts of multiple characteristics. For example, Gibbs et al. (2002) use a water quality variable that accounts for lake size in conjunction with water clarity, arguing that their variable is more robust because it accounts for more of the lake's characteristics.

III.A.4. Human Health

HABs can cause a variety of adverse health effects (in humans and animals) through direct contact with skin during recreation, consumption through drinking water, or consumption of contaminated shellfish, which can result in neurotoxic shellfish poisoning and other effects. According to Davenport and Drake (2011), the HABs in Grand Lake St Marys (described in Section III.A.1) resulted in 23 reported cases of human illnesses and dog deaths. Additionally, proximity to coastal areas where red tide conditions are present may lead to respiratory illness through inhalation of associated airborne toxins (through beach visitation, for example) (Hoagland et al. 2009).

Hoagland et al. (2009) assessed the relationship between red tide blooms and emergency room visits for respiratory illnesses in Sarasota County, Florida and developed estimates of the associated costs. Controlling for other factors that may explain emergency room visits,[16] the authors used a statistical exposure-response model to estimate that there are approximately 39 annual emergency room visits due to red tide during low bloom levels and 218 during high bloom levels. Based on estimated medical treatment costs of $58 to $240 per illness and lost productivity of $335 per illness (for 3 days), red tide events in Sarasota County result in $21,000 to $138,600 in human health impacts.

Hoagland et al. (2009) noted that their study was limited to emergency room visits and excluded the impacts of milder cases of respiratory illnesses. The economic impacts of these cases are likely to be small on an individual case basis (for instance, requiring over-the-counter medicine purchases or short-term loss of work or leisure time; Hoagland et al. 2009), but could be significant when aggregated. Additionally, Hoagland et al. (2009) did not account for the pain and suffering associated with illnesses, nor for the potential for red tide to contribute to long-term chronic respiratory illnesses. Table III-4 summarizes the economic impacts of HABs with respect to human health.

Table III-4. Estimated Human Health Economic Impacts

Study	State	Waters	Water Quality	Health Impacts (2012$)[1]
Hoagland et al. (2009)	FL	Coast	HABs[2]	• $21,000 per year for low bloom levels. • $138,600 per year for high bloom levels.

HABs = harmful algal blooms
[1] *All impacts updated to 2012$ using the Consumer Price Index.*
[2] *Varying level of HABs causing respiratory illnesses.*

[16] Including low temperatures, a high incidence of influenza outbreaks, high pollen levels, and large numbers of tourists.

III.A.5. Anecdotal Evidence and Additional Studies

Additional studies may provide supporting information on the adverse impacts of anthropogenic nutrient loading. These include both anecdotal evidence of adverse economic impacts from nutrient pollution, such as newspaper accounts of algal bloom events, and additional studies that use broader assumptions or methodologies than those meeting this report's screening criteria. Appendix A provides more detail on the anecdotal evidence and additional studies.

III.B. Increased Costs

The studies summarized in this section document the increased cost associated with anthropogenic (human-caused) nutrient pollution. The majority of these costs will be incurred by government entities including federal, state, and local governments, or passed on to consumers through utility bills, for example.

III.B.1. Drinking Water Treatment

Excess nutrients in source water for drinking water treatment plants can result in a number of potential health risks and increased treatment costs. For example, algal blooms can result in taste and odor issues which often require treatment plants to add granular or powdered activated carbon. Drake and Davenport (2011) indicate that some municipalities are purchasing equipment to monitor for and treat the toxins associated with HABs. Excess algae also produce precursors to carcinogenic and toxic disinfection byproducts. These byproducts form when disinfectants used in water treatment plants (e.g., chlorine) react with natural organic matter, such as decaying vegetation or algae. The EPA regulates these disinfection byproducts due to their harmful effects on human health. Hence, increased concentrations could result in increased treatment costs for removal.

Lastly, high levels of nitrates in source water above the maximum contaminant level are a concern because nitrates have been linked to health effects such as methemoglobinemia, a condition involving a decrease in the ability of red blood cells to carry oxygen, also known as blue baby syndrome (Deana et al., 2006).

Higher pollutant concentrations of nutrients and algae in the source water result in higher treatment costs for municipalities and their residents due to the additional treatment needed to remove the pollutants. For example, drinking water treatment plants may need to install additional process controls or increase chemical addition to target nutrients or algae in source waters. However, studies documenting these increased costs are not readily available. Table III.5 shows the results from the two recent studies that met the screening criteria for this project. Numerous anecdotal reports on the increased costs and impacts associated with excess nutrients in source water are in Appendix A.

Drake and Davenport (2011) reported increased drinking water treatment costs for Grand Lake St. Marys in Ohio associated with a 2010 blue-green algae outbreak, which prompted recreational, human health, and fish consumption advisories for the lake. As of October 2010, the City of Celina estimated that it had spent $13.1 million, of which $3.6 million was total operations and maintenance (O&M) costs to date to install treatment controls and set up toxic algae testing. This estimate is conservative and does not account for the alum, lime, and sludge costs associated with the high organic loads resulting from the algal bloom.

EPA Region 6 tasked a contractor, The Cadmus Group Inc. (2014), who compiled data from the City of Waco, Texas, to estimate the total costs incurred from 2002 through 2012 to address poor drinking water quality due to excess nutrients. They estimated that the city incurred $70.2 million in costs, with 92% attributable to upgrades to the drinking water treatment process, 4% for nutrient-related watershed water quality monitoring, 2% for increased treatment chemical usage, 1% for influent and treated water monitoring beyond regulatory sampling requirements, and 1% for increased energy usage related to the treatment plant upgrades. Also, they estimated that the City of Waco potentially lost up to $10.3 million in revenue due to taste and odor problems resulting in decreased water sales to neighboring communities prior to the treatment plant upgrades (although some of the lost sales might have been attributable to drought conditions).

Table III-5. Increased Drinking Water Treatment Costs Attributable to Algal Blooms

Date	State	Waters	Water Quality	Costs (2012$)[1]
2010	OH	Grand Lake St. Marys	Blue-green algae outbreak	$13,080,000 ($3,570,000 in O&M to date)[2]
2002-2012	TX	Lake Waco	High total phosphorus and chlorophyll-a concentrations	Watershed Monitoring = $2,597,118 Influent/Treated Water Monitoring = $740,705 Chemical Usage = $1,169,151 Plant Upgrades = $64,877,721 Plant Energy Costs = $812,755 Lost Revenue from purchased water = $10,300,000

Source: Davenport and Drake (2011) for Ohio; The Cadmus Group Inc. (2014) for Texas.
[1] *Costs updated to 2012$ using the construction cost index.*
[2] *For treatment installation, toxic algae testing set-up, and total O&M (excludes alum, lime, and sludge costs).*

III.B.2. Mitigation Costs in Lakes[17]

In this section, the term “mitigation” refers to approaches that attempt to address the nutrients in the waterbody directly, prevent the manifestation of the nutrient problem (e.g., limit nutrient availability, uptake, and formation of algal blooms), and moderate algal blooms and their impacts in the system. Other terms for these approaches include waterbody management (as opposed to watershed management where nutrients are controlled at sources in the watershed), or in-lake/in-system management. Most of the examples found were done in lakes and freshwater systems at varying scales. There were no examples in estuarine or marine waters at this time.

The reader should note that mitigation costs may or may not reflect full external costs of nutrient pollution. In some instances it might cost more to mitigate damage than it would be worth to the affected community to simply live with a degraded waterbody. In other instances, mitigating damages might not reflect full costs if, for example, even after waters were restored to their original conditions fish populations might still not have fully recovered. The figures that follow might be treated with caution for these reasons. However, the fact that many of these costs are, in fact, incurred, shows that there would be savings if nutrients were reduced in many contexts.

Phosphorus that enters a waterbody with poor outflow or circulation will settle and accumulate in the bottom sediments, acting as a source of phosphorus loading to the water column. Uncontrolled inputs over long periods of time (e.g., from agricultural or urban runoff) can exacerbate this legacy load. These releases often lead to persistent algal blooms, eutrophication, and macrophyte growth.

[17] All unit costs in this section are presented per acre *treated* (not per acre of lake area).

Source reduction efforts in these watersheds will do little to reduce these effects due to the continued release of legacy phosphorus from the sediments.

Thus, mitigation measures are often needed to reduce phosphorus loads and achieve the desired water quality. The costs associated with these measures can be significant. Table III-6 summarizes studies documenting the costs of various mitigation measures that have been used in or considered for particular lakes. The details are provided after the table.

Table III-6. Mitigation Costs Associated with Excess Phosphorus in Lakes

Study	State	Waterbody	Description	Capital Costs (2012$)[1]	Annual O&M Costs (2012$/yr)[1]
Aeration System					
Berkshire Regional Planning Commission (2004)	MA	Onota Lake	Deep-hole system.	$355,621–$411,772	$49,912
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Hypolimnetic aeration only. Based on vendor quote.	$94,907	$5,260
ENSR Corporation (2008)	MA	Lovers Lake & Stillwater Pond	Artificial circulation	$117,195	$7,990
Chandler (2013)	MN	Twin Lake	Solar powered system.	$139,157	$4,945
Chandler (2013)	MN	Twin Lake	Bubbler system.	$232,424	$34,616
City of Lake Stevens (2013)	WA	Lake Stevens	Actual costs over 6 years, includes power consumption, staffing, and repairs.	Not reported	$35,000–$110,000
Alum Treatment					
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Treatment to last 15 years for application area of 19 acres for Lovers Lake and 9.25 acres for Stillwater Pond.	$211,676–$243,667	$0
Barr (2005)	MN	Keller Lake	Treatment for the whole lake, based on lake-specific data.	$58,780	$0
Barr (2005)	MN	Kohlman Lake	Treatment for the whole lake, based on lake-specific data.	$165,759	$0
Barr (2012)	MN	Spring Lake	Treatment for the whole lake, based on lake-specific data; intended to last 10–32 years.	$986,000–$1,086,000	$0
Chandler (2013)	MN	Twin Lake	Alum addition to 19 of the 20 acres of the lake twice in 3 years (intended to last 10–20 years).	$146,377	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (35 of 776 acres); intended to last 5 years.	$22,687	$0
Osgood (2002)	SD	Lake Mitchell	Based on $150,000 in the first year, $120,000 for 2 years after, and $100,000 per year thereafter.	$127,623–$238,246	$0
Herrera Environmental Consultants (2003)	WA	Green Lake	Intended to last 10 years.	$1,883,115	$0

Study	State	Waterbody	Description	Capital Costs (2012$)[1]	Annual O&M Costs (2012$/yr)[1]
King County (2005)	WA	Lake Hicks	Also includes public outreach costs.	$54,762	$0
Burghdoff and Williams (2012)	WA	Lake Ketchum	Whole lake treatment intended to last 4 years.	$198,015	$0
Burghdoff and Williams (2012)	WA	Lake Ketchum	Costs represent single dose for a year to treatment the water column only (not sediment).	$36,745	$0
Tetra Tech (2004)	WA	Lake Lawrence	Whole lake treatment intended to last 10 years.	$986,921	$204,192
Cedar Lake Protection and Rehabilitation District (2013)	WI	Cedar Lake	Partial lake treatment; costs represent 2 applications over 10 years.	$2,175,881	$0
Hoyman (2011)	WI	East Alaska Lake	Whole lake treatment; life of treatment not specified.	$168,221	$0
Barley Straw					
Chandler (2013)	MN	Twin Lake	Costs represent a yearly cost.	$11,057	$0
Biomanipulation					
Chandler (2013)	MN	Twin Lake	Costs based on a total of four stockings conducted in years 1, 2, 4, and 6 over a 10-year period.	$279,403	$0
Dredging					
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Removal of 32,850 cubic yards from Lovers Lake and 28,500 cubic yards from Stillwater Pond; intended to last 10 years or less.	$1,546,246	$0
Barr (2005)	MN	Keller Lake	Dredging for the whole lake.	$628,944–$1,390,731	$0
Barr (2005)	MN	Kohlman Lake	Dredging for the whole lake.	$968,692–$2,143,112	$0
Chandler (2013)	MN	Twin Lake	Dredging for the whole lake.	$2,541,824	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (300 out of 776 acres).	$5,905,143–$9,794,369	$0
Tetra Tech (2004)	WA	Lake Lawrence	Includes alum treatment; intended to last >50 years.	$28,124,132	$1,404,218
Herbicide Treatment					
Berkshire Regional Planning Commission (2004)	MA	Onota Lake	Represents actual costs for application of the herbicide SONAR over the whole lake, with follow-up spot treatment.	$172,264	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (35 out of 776 acres); intended to last 5 years.	$29,169	$0
Hypolimnetic Withdrawal					
Chandler (2013)	MN	Twin Lake	Lasts 20 years.	$583,532	$39,561

Capital costs = fixed, one-time expenses incurred on the purchase of land, buildings, construction, and equipment used in the production of goods or in the rendering of services. O&M = Operation and Management.

[1] *Costs updated to 2012$ using the Consumer Price Index.*

The studies described in this section meet the evaluation criteria in Section II.E. Table A-3 in Appendix A summarizes additional anecdotal evidence of mitigation costs. Note that mitigation in the absence of controlling inputs from existing point and non-point sources will not likely be effective in the long term because the phosphorus will continue to accumulate in sediments, resulting in the need for future mitigation.

There are several mitigation techniques that can be used to reduce legacy nutrient loads, most of which primarily target the sediment. Costs for these measures are waterbody specific and depend on the selected technique, extent and history of nutrient pollution, past mitigation measures employed (if any), hydrologic characteristics (e.g., water depth, circulation), climate/rainfall, and water quality (e.g., acidity, hardness, presence of other contaminants). Thus, it may be difficult to compare costs across waterbodies and technologies.

Aeration System— Aeration involves the addition of oxygen to the hypolimnion layer (e.g., the lake bottom waters) to reduce the release of phosphorus from lake sediment. Sediment-bound phosphorus is most soluble, and thus readily released, in oxygen-poor waters. Oxygenating these waters results in less phosphorus released into the water column from sediments. The effectiveness of aeration in controlling algae depends on both sufficient oxygen to meet the hypolimnetic demand and an adequate supply of phosphorus binders either naturally or through the addition of reactive aluminum or iron compounds to bind phosphorus before it enters the water column. Aeration systems typically require installation of capital equipment and annual maintenance and operation of that equipment.

Berkshire Regional Planning Commission (2004) estimated costs of a deep-hole aeration system for Onota Lake in Massachusetts. The system was estimated to cost $355,621–$411,772 and included three columns, air lines, ballast, a compressor house, compressor, ventilation system, electric circuitry, and air valving system. Annual O&M is approximately $49,912 and included an annual service contract. Unit costs based on treating this 617-acre lake were approximately $580 to $670 per acre for capital and $81 per acre per year for O&M. Berkshire Regional Planning Commission (2004) did not report the expected useful life of the aeration system equipment.

ENSR Corporation (2008) estimated costs for hypolimnetic aeration for two lakes in Massachusetts (Lovers Lake and Stillwater Pond). Based on vendor quotes, they estimated capital costs of $94,907 and annual O&M of $5,260 for both lakes. ENSR Corporation (2008) also estimated costs for artificial circulation (which operates under the same concept as aeration) for the lakes of $117,195 in capital and $7,990 per year for O&M. These estimates equate to unit costs associated with aeration techniques of approximately $1,700–$2,100 per acre for capital and $95–$140 per acre per year for 55.5 total acres (37.7 for Lovers Lake and 17.8 for Stillwater Pond). ENSR Corporation (2008) estimated a useful life for the aeration equipment of 15 years.

Chandler (2013) estimated costs for two aeration systems for Twin Lake in Minnesota: a solar-powered system and a bubbler system. The Solar Bee solar-powered mixing system consists of a tube with an impeller that pulls water from the bottom of the tube to the surface. The colder water then plunges outside of the tube, causing the lake to de-stratify and presumably improve dissolved oxygen. The tube can be placed at a depth below the thermocline to access cold water. Capital costs are $139,157, and O&M costs are minimal because the system is solar-powered, and only labor associated with spring placement and fall removal is necessary (for an estimated annual cost of $4,945). Unit costs for the 20-acre lake are approximately $6,958 per acre for capital and $247 per acre per year for O&M. Chandler (2013) and were based on an estimated useful life for the solar-powered aeration system of 20 years.

The alternative aeration system considered by Chandler (2013) was a bubbler system, which consists of flexible tubing (soaker hoses) installed at the lake bottom and pumps that provide compressed air to the tubing. Chandler (2013) estimated capital costs and O&M costs of $232,424 and $34,616 per year, respectively, based on a past lake aeration project. This equates to $11,600 per acre for capital and $1,731 per acre per year for O&M. Chandler (2013) estimated a useful life for the bubbler aeration system of 20 years.

The City of Lake Stevens (2013) in Washington reported the actual annul O&M costs associated with its existing aeration system over the past six years. Historically, operating costs were around $35,000 per year for power consumption and staffing. However, recently, due to repairs and replacement parts, operating costs have increased to about $110,000 per year. Unit costs for the 1,013-acre lake range from $35–$109 per acre per year. The City of Lake Stevens (2013) did not specify the useful life of the aeration system.

Alum Treatment— Aluminum sulfate, otherwise known as alum, is a chemical commonly used to mitigate nutrient pollution in lakes. When added to the water column, the alum precipitates as a floc, which removes phosphorus from the water. The floc then settles on the sediment at the bottom of the lake. If enough alum is added, the settled floc forms a barrier that prevents the release of phosphorus from sediment. Costs for alum treatment vary based on the number of applications needed over a given timeframe. In most cases, the time period over which the alum treatment will last is highly lake-specific and depends on the extent of controls on existing inputs, initial alum dose, natural water circulation, and extent of phosphorus pollution/target concentrations or reductions.

Several studies have examined the use of alum as a mitigation technique for phosphorus in lakes. Barr (2005) evaluated alum treatment as a potential mitigation technique for internal phosphorus loading in two Minnesota lakes. For Kohlman Lake, which had an estimated sediment internal loading rate of 9.7 $mg \cdot m^{-2} d^{-1}$, the study recommended alum treatment as a feasible option, with an estimated capital cost of $165,759 for a single application. This equates to unit costs of $2,240 per acre to treat all 74 acres of the lake. The authors estimated alum treatment costs for Keller Lake to be $58,780 for a single application, or $816 per acre to treat all 72 acres of the lake. However, they recommended other mitigation options due to the lake's lower sediment internal loading rate. Barr (2005) does not indicate how long the alum treatment will last before another treatment would be necessary.

Barr (2012) calculated the alum dose necessary to treat phosphorus in the sediment of Spring Lake, Minnesota. The study based its dosage calculation on treating the upper 6 cm of sediment across the entire lake, and estimated a capital cost of $986,000–$1,086,000. The treatment is for the entire 409 acres of the lake, resulting in unit costs of $2,411 to $2,655 per acre. The range in costs represent the difference between a one-time full application of alum and breaking the full dose up into three separate applications (higher costs because there is more labor and start-up associated with each application even though the amount of alum does not change). Barr (2012) estimates that the alum treatment could last 10 to 32 years.

Burghdoff and Williams (2012) conducted a study to identify the best methods of controlling the internal and external phosphorus sources and resulting algae blooms in Lake Ketchum, Washington. Authors showed that alum treatment of the sediment could reduce average lake phosphorus concentration from 277 μg/L to 71 μg/L over a four-year period. They estimated the costs of treatment for phosphorus in the upper 10 cm of sediment to be $198,015. They also estimated costs for treating only the water column with alum to be $36,745 annually. Note that while the sediment alum treatment is higher, it lasts for 4 years, whereas the water column alum addition must be repeated each year. Both treatment options would treat all 25.5 acres of the lake, resulting in unit costs of approximately $7,800 per acre and $1,400 per acre, respectively.

The Cedar Lake Protection and Rehabilitation District (2013) estimated the alum dose necessary to treat phosphorus associated with excess algae growth in Cedar Lake, Wisconsin. The study recommended a partial lake treatment of the upper 6 to 8 cm of sediment at water depths greater than 20 feet. The authors estimated that the costs associated with this recommendation would be nearly $2.2 million for two applications, with a useful life of approximately 10 years, and would reduce phosphorus concentrations from 0.068 mg/L to 0.030 mg/L. The Cedar Lake Protection and Rehabilitation District (2013) did not specify the total number of acres to be treated so unit costs cannot be estimated.

Chandler (2013) studied the feasibility of alum treatment for the eutrophic conditions caused by phosphorus in Twin Lake, Minnesota. Chandler (2013) concluded that alum addition for 19 of the 20 acres of the lake twice in 3 years would cost $146,377 or approximately $7,700 per acre, and reduce phosphorus concentrations from 70 μg/L to 20 μg/L.

ENSR Corporation (2008) assessed alum treatment as a technique to reduce the release of phosphorus from sediment in Lovers Lake and Stillwater Pond, Massachusetts. The authors indicated that partial lake treatment (19 of 37.7 acres for Lovers Lake and 9.25 of 18.7 acres for Stillwater Pond) would provide sufficient treatment for 15 years at a one-time cost of $211,676–$243,667 or $7,493–$8,625 per acre.

Herrera Environmental Consultants (2003) reported on the use of alum to treat phosphorus associated with periodic blue-green algae blooms in Green Lake, Washington. The study determined that a 23 mg/L alum dose would reduce phosphorus concentration from 13 μg/L to 2 μg/L for about 10 years at a one-time cost of approximately $1.9 million or $7,261 per acre to treat all 259 acres of the lake.

Hoyman (2011) studied the feasibility of alum treatment for reducing internal phosphorus loading in East Alaska Lake, Wisconsin. The authors concluded that an alum application rate of 132 g/m^2 to areas of the lake with depths greater than 10 feet, and 40 g/m^2 to areas with depths between 5 and 10 feet would provide a 90% reduction in internal phosphorus loading. The study estimated the one-time cost of this treatment at $168,221 or $4,143 per acre to treat the 41-acre lake.

King County (2005) identified alum treatment as a management strategy for reducing phosphorus concentrations in Lake Hicks, Washington. The goal was to reduce phosphorus concentrations to less than 20 μg/L, at which point the lake would no longer be listed as impaired for nutrients. The study reported that alum treatment for Lake Hicks, including pre- and post-treatment monitoring, would cost $54,762 for a single application or $13,690 per acre to treat 4 acres. The study did not specify how long the alum treatment was expected to last, however, it references Welch and Cooke (1999), which states that benefits of alum treatment could last for more than 10 years.

Osgood (2002) gave recommendations on an alum treatment plan for Lake Mitchell, which serves as the water supply for the City of Mitchell, South Dakota. The report concluded that three years of whole-lake alum applications (acres not specified) would be sufficient to reduce phosphorus concentrations in the lake from 241 μg/L to 90 μg/L, with per application costs of $238,246 for the first year, $204,042 for the next two years, and $127,623 annually thereafter. Osgood (2002) does not specify how long the annual treatments would last.

Tetra Tech (2004) examined the feasibility of alum treatment as a method for the inactivation of phosphorus cycling in Lake Lawrence, Washington. The authors estimated that a 6-day, whole-lake alum treatment (330 acres) would provide water quality benefits lasting more than 20 years. They reported that the one-time capital cost of treatment would be $986,921 or $2,991 per acre and the cost of 80 days of monitoring per year would be $204,192 or $619 per acre per year.

The LA Group (2001) considered alum treatment as a technique for the management of aquatic vegetation in Cossayuna Lake. The study reported that treating 35 of the lake's 776 acres with alum would cost $22,687 for a single application or $648 per acre. This cost covers a five-year planning period.

Barley Straw— Barley straw application is a method in which straw is placed along the edge of waterbodies so that it degrades and releases a chemical that inhibits new algal growth. Barley straw does not remove nutrients; as such, it needs to be applied annually to be effective (Chandler, 2013). Chandler (2013) evaluated barley straw as a potential mitigation strategy for Twin Lake in Minnesota. Assuming a straw application rate of 300 lbs/acre, and accounting for delivery, materials, and labor, the study calculated an annual application cost of $11,057, or $553 per acre for the 20-acre lake.

Biomanipulation— Biomanipulation involves the introduction of piscivores to control the population of planktivorous fish, which feed on zooplankton. Fewer planktivorous fish allow zooplankton populations to thrive and consume more algae (Chandler, 2013). Chandler (2013) developed a plan to use biomanipulation to control algae in Twin Lake in Minnesota. The plan consisted of three parts: removing rough fish (planktivores), stocking the lake with pike and bass (piscivores), and monitoring fish migration to determine if the stocking was successful. The authors estimated that the total costs for this plan, assuming a total of four stockings, would be $279,403, or $13,970 per acre for the 20-acre lake.

Dredging— Dredging can be used to remove phosphorus trapped in lake-bottom sediment, which reduces internal phosphorus cycling. Barr (2005) investigated dredging as an option to remove phosphorus from Keller and Kohlman lakes in Minnesota. The study determined that dredge depths of 15 cm in Kohlman Lake and 10 cm in Keller Lake would be necessary to remove excess total phosphorus. The authors estimated the total capital cost of dredging and sediment disposal to be $968,692–$2,143,112 for the 74-acre Kohlman Lake and $628,944–$1,390,731 for the 72-acre Keller Lake; unit costs are $13,090 to $28,961 per acre for Kohlman Lake and $8,735 to $19,316 per acre for Keller Lake. The authors did not report how long the impacts of dredging would last.

Chandler (2013) considered dredging as an option to reduce phosphorus concentrations in Twin Lake, Minnesota. The report determined that sediments from dredging would have to be disposed offsite because of limited space surrounding the lake. Estimated total capital costs were $2,541,824, based on a dredging depth of 15 cm across the 20-acre lake, construction of an onsite dewatering facility, and shipment of dewatered solids to a landfill; unit costs are $127,091 per acre. Chandler (2013) did not report how long the impacts of dredging would last.

ENSR Corporation (2008) evaluated a plan to dredge sediment from Lovers Lake and Stillwater Pond in Massachusetts. The study determined that not all sediments were nutrient rich, and thus full-lake dredging was not necessary. Based on dredging two feet of sediment at water depths greater than 20 feet for a total of 19 acres, capital costs would be $1,546,246 (for unit costs of $81,339 per acre). The authors stated that they expect the benefits of dredging to last for at least 10 years.

Tetra Tech (2004) reported on the feasibility of dredging Lake Lawrence, Washington. They recommended dredging a total of 2,100,600 cubic yards of sediment at depths of 0–2.5 m across the lake. Total capital costs for dredging 330 acres, sediment transport and disposal, and post-dredging alum treatment would be $28,124,132, and total O&M costs would $1,404,218. Unit costs are $85,225 per acre for capital and $4,255 per acre for O&M. The authors expected that the benefits of the dredging and alum treatment would last for more than 50 years.

The LA Group (2001) estimated costs for a partial dredging of Cossayuna Lake in New York. Estimated capital costs to excavate 4 to 6 feet of sediment across 300 of the lake's 776 acres were between $5,905,143 and $9,794,369; unit costs were estimated to be $19,683 to $32,647 per acre. The authors did not report how long the dredging benefits would last.

Herbicide/Copper Sulfate Treatment— Herbicide treatment is used to remove nuisance algae species caused by the presence of excess nutrients. The Berkshire Regional Planning Commission reported that in 1998, approximately one-third of Lake Onota was covered with milfoil and was virtually unusable for recreational purposes. In 1999, due to the critical need to combat the milfoil, the City implemented a whole lake treatment with the herbicide SONAR. In 2000, they conducted follow-up spot treatment. The total cost of the treatment was $172,264, and the program successfully eliminated well over the contractually required 90% of the milfoil. Unit costs for the 617-acre lake are $279 per acre.

Copper sulfate is an algaecide that kills excess algae in lakes. Note that this treatment is not feasible in all waters because fish populations in waters with total alkalinity values less than 50 mg/L are sensitive to copper. The LA Group (2001) estimated the cost of annual copper sulfate doses to compare to the cost of alum treatment of 35 acres out of 776 acres in Cossayuna Lake in New York. They estimated the total cost of treatment over 5 years as $29,169, assuming annual doses, which translates to approximately $833 per acre for 5 years of treatment.

Hypolimnetic Withdrawal— Hypolimnetic withdrawal involves the direct removal of phosphorus-laden lake bottom waters. A hypolimnetic withdrawal system includes a pipe and perforated riser that is installed along the lake bottom, near the deepest point. The pipe connects to a shoreline treatment system consisting of pumps, tanks to hold chemicals, and a clarifier to settle treated water (Chandler, 2013). In smaller lakes, water must be added back in to maintain lake levels. Chandler (2013) estimated costs of hypolimnetic withdrawal for Twin Lake in Minnesota to be $583,532 for capital (including construction, engineering and design, and contingency) and $39,561 per year for O&M (including electricity, chemicals, and settled flocculent disposal); unit costs for this treatment are approximately $29,000 per acre for capital and $2,000 per acre per year for O&M for the 20-acre lake. Chandler (2013) indicated that the technique should last 20 years.

III.B.3. Restoration Costs

In addition to economic impacts and costs associated with nutrient pollution in surface waters, there can also be costs for activities that aim to restore impaired waterbodies. This section provides illustrative information on potential costs to public sector entities that implement programs to deal with nutrient pollution.

Development and Implementation of Total Maximum Daily Loads (TMDL) and Watershed Plans

Under Section 303(d) of the Clean Water Act, states and tribes are required to develop lists of impaired waters. The states and tribes identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards. They are then required to establish priorities for the development of TMDLs for waters listed on the Section 303(d) list. The costs for the development and implementation of TMDLs and watershed plans developed for Clean Water Act section 319 purposes vary based on watershed size and complexity. For example, in the

Chesapeake Bay watershed the Chesapeake Bay Regulatory and Accountability Program Grants, which resulted from Executive Order 13508, help jurisdictions develop new regulations, design TMDL watershed implementation plans, reissue and enforce permits, and provide technical and compliance assistance to local governments and regulated entities. The amounts each jurisdiction receives in grants (federal and state combined) range from approximately $900,000 per year in West Virginia to $5.7 million per year in Maryland.

However, developing a TMDL and/or implementation plan for a much smaller watershed is likely to cost much less. U.S. EPA (2001) estimated the cost of developing TMDLs based on performing eight basic steps:

- Characterizing the watershed
- Modeling and analyzing the waterbody and its pollutants to determine the reduction in the pollutant load that would eliminate the impairment
- Allocating load reductions to the appropriate sources
- Preparing an implementation plan
- Developing a TMDL support document for public review
- Performing public outreach
- Conducting formal public participation and responding to it
- Managing the effort (including tracking, planning, legal support, etc.).

As shown in Table III-7, U.S. EPA (2001) provides unit costs of developing TMDLs at different levels of aggregation: a single cause of impairment, the need for multiple TMDLs, and a submission that may range from a single TMDL for a single waterbody to many TMDLs for all the waterbodies in a watershed. The estimates reflect TMDL costs from 35 states and cover more than 60 types of causes submitted over the period April 1998 through September 2000. These estimates in Table III-7 do not cover the implementation of the TMDLs.

Table III-7. Costs of Developing TMDLs

Level of Aggregation	Typical Cost Range
Cost per single cause of impairment (for single TMDL)	$6,000–$154,000 (2000$)[1]
Cost per single waterbody (for single TMDLs to multiple TMDLs)	$26,000 to >$500,000
Cost per submission (for single waterbody to multiple waterbodies)	$26,000 to >$1,000,000

Source: U.S. EPA (2001).

[1] *Estimates reflect TMDL costs from 35 states and cover more than 60 types of causes submitted over the period April 1998 through September 2000.*

Setting Up Programs for Water Pollutant Trading and Offsets

Water pollutant trading is an approach that can be used to achieve water quality goals by allowing sources to purchase equivalent or better pollution reductions from another source, typically at a lower cost. Similarly, water quality offset occurs where a source implements controls that reduce the levels of pollution for the purpose of creating sufficient assimilative capacity to allow for the discharge of a pollutant for which they may otherwise have to install more expensive treatment or controls. The use of trading and offsets can improve nutrient-impaired waterbodies potentially at lower costs. Several states have developed policies and programs to encourage trading and offsets as a means to reduce the burden on sources in complying with TMDLs and applicable water quality criteria.

Breetz et al. (2004) performed a comprehensive survey of water quality trading and offsets in the United States. As part of the survey, the costs to administer the trading and offset programs were compiled along with general information about the program. Table III-8 presents a summary of the costs associated with trading and offsets related to nutrients.

Table III-8. Summary of Costs to Administer Nutrient Trading and Offset Programs

Program Name (Location)	Type of Program	Nutrient(s) Involved	Description of Costs (2012$)
Boulder Creek Trading Program (CO)	Offset	Nitrogen	The total cost was estimated at $1.58–$1.70 million. Costs included the costs of gathering data for planning and evaluation, construction, materials, labor, and time. The overall cost was brought down by the donation of volunteer labor, time, materials, and land easements from landowners.
Chatfield Reservoir Trading Program (CO)	Trading	Phosphorus	A $122 application fee to cover administrative costs is required for point sources to apply for increased discharge through trading. Credits that enter the pool are sold at a price that reflects the cost of nonpoint-source reduction projects, costs associated with the pooling program, and costs incurred by the Authority to administer the trading program. Exact costs are unknown, but the monitoring program was estimated to cost $71,000/year.
Cherry Creek Basin (CO)	Trading	Phosphorus	Coming from a combination of property taxes and user fees, the budget for 2003 was $1.7 million, of which at least 60% had to be spent on the construction and maintenance of pollution reduction facilities. The remaining 40% is used in research, planning documents, technical reports, and administrative costs. State grants finance a smaller portion of the work, particularly that involving educational campaigns about nonpoint-source pollution and construction of pollution reduction facilities.
Long Island Sound (CT)	Trading	Nitrogen	The trading program carried out two years of credit exchange with relatively limited financial resources, besides the state and federal funds used to implement nitrogen removal projects. The Connecticut Department of Environmental Protection employs the equivalent of two full-time employees to work on the exchange; the advisory board does not receive monetary compensation.
Rahr Malting Company Permit (MN)	Offset	Nitrogen and phosphorus	During the two-year permitting phase, Rahr spent about $20,000 ($14,600 for consultants and $5,500 for staff time), while the Minnesota Pollution Control Agency (MPCA) spent about $63,000 on staff time. During the implementation phase, Rahr spent about $2,700 on staff time, the MPCA spent about $40,000 on staff time, a local citizen's group spent about $900, and nonpoint sources spent about $600 on legal assistance. The grand total for transaction costs during these two phases was about $128,000, 81% of which were borne by the MPCA as it designed the overall program structure.

Program Name (Location)	Type of Program	Nutrient(s) Involved	Description of Costs (2012$)
New York City Watershed Program (NY)	Offset	Phosphorus	For development of the comprehensive strategies in the Croton System, the New York City Department of Environmental Protection allocated up to $1.2 million to each county required to develop a water quality protection plan.
Tar-Pamlico Nutrient Reduction Trading Program (NC)	Trading	Nitrogen and phosphorus	The Tar-Pamlico Basin Association gave $182,000 to the state Department of Environmental Management during Phase I to fund a staff position, and the trading ratio includes 10% for administrative costs.
Great Miami River Watershed Water Quality Credit Trading Pilot Program (OH)	Trading	Nitrogen and phosphorus	Estimated 3-year project cost of $2,430,810 including $607,000 to fund BMPs. The program receives in-kind support primarily in the form of water quality monitoring, and the training of soil and water conservation professionals by other organizations.

Source: Breetz et al. (2004)

III.B.4. Anecdotal Evidence and Additional Studies

Similar to Section III.A.5, additional anecdotal evidence and studies related to increased costs of nutrient pollution, including drinking water treatment costs and mitigation costs are presented in Appendix A.

III.C. Data Limitations

As described in the previous section, there are a number of studies documenting the economic impacts of nutrient pollution in surface waters across the United States (Table III-9). These studies demonstrate that the impacts associated with surface water nutrient pollution can be very damaging to locally important economic industries (e.g., tourism in Florida communities, lakefront real estate in areas of Maine, and others). However, a number of additional reports do not meet the screening criteria for documentation of impacts due to various reasons (e.g., method not clearly described, data sources not identified or documented). These additional studies (also reflected in Table III-9) suggest that the economic impacts from nutrient pollution may be more widespread than the screened studies indicate.

Table III-9. Summary of Nutrient Pollution Cost Documentation

Impact	Number of Studies Found (Number that Match Criteria)	Waterbody Types	Locations
Tourism and recreation	13 (7)	Lakes, bays, rivers, coasts	MD, OH, FL, TX, WA; national
Commercial fishing	9 (5)	Bays, rivers, coasts	ME, MD, NC, FL, TX, AK; national
Property values	15 (9)	Lakes, rivers, coasts	ME, NH, VT, MD, OH, SC, FL, WI, MN, HI; national
Human health	2 (1)	Coasts	FL; national
Drinking water treatment costs	11 (2)	Lakes, rivers, coasts	OH, IA, FL, CA, KS, TX; national
Mitigation costs	31 (31)	Lakes	MN, MA, WA, WI, SD, NY
Restoration costs	14 (14)	Watersheds	CT, NY, PA, OH, MN, CO, CA, OR; national

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IV. Cost of Nutrient Pollution Control

Attaining numeric or narrative water quality standards for nutrients entails the deployment of nutrient pollution controls for point and/or nonpoint sources in most waterbodies. This section summarizes the data and information collected from recent studies related to the costs for treatment systems and other controls that have been employed by point and nonpoint sources to reduce the discharge of nutrients to surface waters. All dollar values were updated to 2012 dollars (2012$) for technologies based on the Construction Cost Index and for best management practices based on the Consumer Price Index.

The types and extent of controls required to reduce nutrient pollution will depend on a number of factors, including for example, the number and types of sources contributing to the pollution requiring controls, geographic location, and stringency of water quality standards. In addition, the extent of the nutrient pollution controls required may also depend on the specific control plans (e.g., TMDLs, watershed plan) established by state and local regulatory authorities. Therefore these factors should be considered prior to use of cost data provided throughout this section.

IV.A. Point Source Control Costs

Point sources include discharges of pollutants from either municipal wastewater treatment plants (WWTPs) or industrial waste treatment facilities directly to surface waters through pipes, outfalls, and conveyance channels. Although these facilities play a vital role in maintaining public health and protecting natural waters by providing waste treatment services to businesses and local communities throughout the United States, they can be significant contributors of nutrient pollution to waterbodies of the United States.

This section summarizes cost and treatment effectiveness information extracted during the literature search for technologies used at point source facilities to control the discharge of nutrients. This section is organized according to the type of point source[18]:

- Municipal WWTPs
- Decentralized treatment systems for small communities
- Industrial wastewater treatment plants.

Most cost data collected during the course of the literature review were normalized to a unit cost based on the information provided in each source; however, a portion of the data collected for treatment of industrial sources of nutrient pollution was not normalized since treatment capacities were not available for individual facilities.

All the studies from which data were extracted include the cost and some measure of nutrient control performance (i.e., effluent concentration and/or percent removal), however the reported costs may not be specific to the associated performance measure for a single pollutant by itself. For

[18] Stormwater discharges from many municipal separate storm sewer systems (MS4s) are regulated under section 402(p) of the Clean Water Act and are required to obtain NPDES permits for their point source discharges. For organizational purposes in this report, and to acknowledge that not all MS4s are regulated at this time, costs and performance for urban and residential runoff are contained in the nonpoint source section.

example, a source may provide the capital cost for a treatment system designed to remove total nitrogen and total phosphorus and the associated treatment performances for both pollutants. However, if the system was designed primarily for phosphorus removal, then the costs will be driven by removal of phosphorus and may overestimate costs for removing nitrogen alone. In the vast majority of cases where performance metrics for both nitrogen and phosphorus were provided for a facility, the source did not indicate which (if any) parameters were design limiting and determinative of final capital and annual operation and maintenance (O&M) costs.

This section limits the discussion of results to descriptive analysis due to the character of the information collected in the literature review. The discussion does not include statistical analysis or modeling of the collected data. Extracted data do not in all cases include independent observations, nor do the data necessarily constitute a representative and statistically valid sample set of nutrient removal facilities throughout the United States. The resulting dataset contains information collected from a diverse set of research articles and reports, each focused on the site-specific situation and needs for nutrient pollution control, and do not constitute a comprehensive survey of nutrient treatment in the United States. In addition, not all cost and performance data correspond to individual facilities. Some studies and reports included cost and nutrient treatment performance curves, but the original data upon which these curves were based were not available. In these cases, multiple data points were extracted from the curves, which served to capture the cost and performance information in the performance curves.

The nutrient control information collected and compiled for this project provides a snapshot of recent cost and performance information for a variety of treatment technologies. This information can be used to gauge the reasonableness of nutrient cost-to-treat estimates developed by government agencies, discharger associations, and other interest groups. This information may also prove a useful starting point in the development of cost estimates and in conducting related literature searches.

IV.A.1. Municipal Wastewater Treatment Plants

Local governments use municipal WWTPs to control and treat sanitary wastewater and sometimes, when the municipality possesses a combined sewer system, stormwater. Some publicly owned treatment works also provide treatment services for discharges from industrial and commercial facilities. This section summarizes the cost and performance data collected for nutrient controls at municipal WWTPs.

As described in Table IV-1, the collected records represent empirical and modeled results for a variety of locations, nutrient types, and WWTPs. Highlights include:

- Cost data represented treatment design capacities for plants ranging from 0.1 million gallons per day (mgd) to 683 mgd.
- Costs associated with the construction of new WWTPs, as well as costs associated with the upgrade, expansion or retrofit of existing facilities were collected.
- Cost data were developed on either the basis of engineering cost estimates (i.e., modeled estimates) or realized, empirical costs for completed facilities.
- Costs data were collected for more than 30 point source control technologies and various combinations thereof.
- Cost data were representative of projects located in a variety of states and geographic regions.

Table IV-1. Summary of Cost and Performance Data for Municipal WWTPs

Category	Number of Records
Total number of records	370
Records which Include Data for Nitrogen and/or Phosphorus [1]	
Nitrogen only	128
Phosphorus only	144
Nitrogen and Phosphorus	98
Records for New Plants or Retrofit/Expansion of Existing Plants	
New construction	47
Retrofit/Expansion	323
Records for a Modeled Estimate or Empirical Data	
Empirical	12
Modeled	358
WWTP Locations	
EPA Region 1	2
EPA Region 2	2
EPA Region 3	53
EPA Region 4	6
EPA Region 5	37
EPA Region 6	3
EPA Region 7	0
EPA Region 8	1
EPA Region 9	1
EPA Region 10	189
Outside United States	2
Location not reported [2]	74
Treatment Capacity	
0.10 mgd – 0.99 mgd	43
1.00 mgd – 4.99 mgd	101
5.00 mgd – 9.99 mgd	25
10.00 mgd– 49.99 mgd	119
> 50.00 mgd	82

[1] *Ninety-eight records include cost and performance data for both nitrogen and phosphorus.*

[2] *A location was registered as "Not Reported" for modeled estimates where the authors did not indicate an assumed location in their methodology. Location information was included for all records associated with empirical results.*

Several sources reviewed during the literature search merit special note for those investigating issues regarding nutrient control at municipal WWTPs. U.S. EPA (2008) provides a broad synthesis of information on nutrient removal at these facilities, including a survey of commonly used treatment technologies, their capabilities and limitations, and planning level costs for treatment technologies. The TMDL report (U.S. EPA, 2001) also documents detailed case studies for plants located in the Chesapeake Bay watershed. In 2011, the Washington State Department of Ecology (WASDE, 2011) produced a technical report wherein they developed cost estimates for a suite of treatment technologies to achieve a number of different effluent quality performance targets. The suite of technologies evaluated was diverse and representative of the variety of existing treatment strategies employed in the United States.

An examination of all collected and compiled cost data for municipal WWTPs (Figures IV-1 and IV-2) shows some economies of scale for nutrient control technologies, demonstrated by the downward sloping diagonal below which there are no observations. Economies of scale are efficiencies gained from operating a larger plant resulting in a reduced average cost per unit of waste treated. These efficiency gains are present for both new plants and for the retrofitting of existing treatment plants.

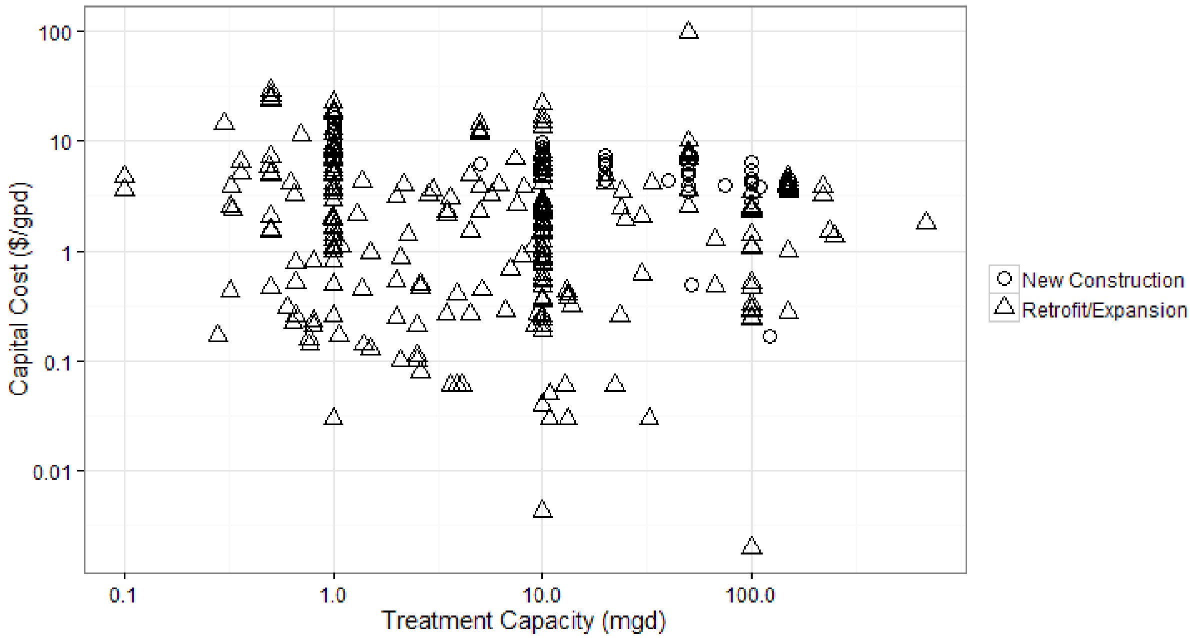


Figure IV-1. Capital costs and treatment capacities for municipal WWTPs (2012$).

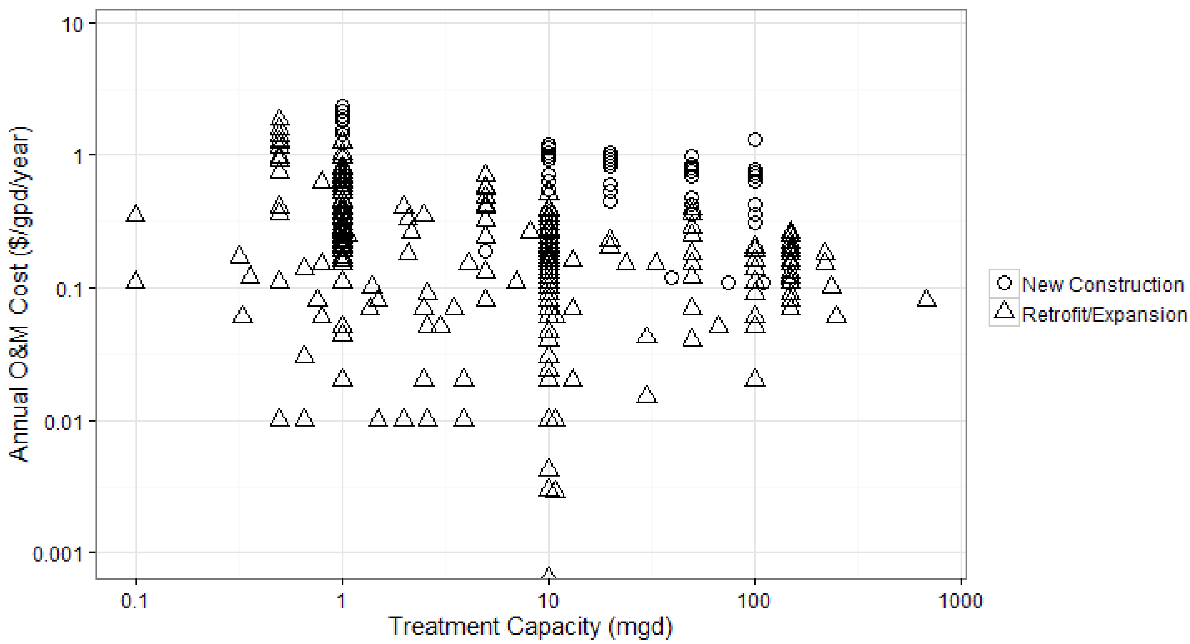


Figure IV-2. Annual O&M costs and treatment capacities for municipal WWTPs (2012$).

Cost and Performance Information – Nitrogen

Cost and performance data were collected and compiled for several forms of nitrogen including total ammonia nitrogen, total inorganic nitrogen, and total nitrogen (TN). Costs and treatment performance ranges for each form of nitrogen are summarized in Table IV-2.

Capital costs (Figures IV-3 and IV-5) were typically less than $25 per gpd, with the exception of a single aerobic lagoon facility with capital costs approaching $100/gpd. Annual O&M costs (Figures IV-4 and IV-6) for total ammonia nitrogen were typically less than $0.10/gpd/year and for TN were frequently less than $0.25/gpd/year, though costs were observed as high as $0.51/gpd/year. Total inorganic nitrogen O&M costs displayed a greater range than those for the other nitrogen parameters with costs ranging as high as $1.85/gpd/year. All costs for total inorganic nitrogen were derived from a single literature source (WASDE, 2011).

Table IV-2. Nitrogen Cost and Treatment Performance for Municipal WWTPs

Effluent Quality (mg/L as N)	Removal Efficiency Range (%)	Capital Cost Range ($/gpd)[1]	Annual O&M Cost Range ($/gpd/year)[1]	Technologies
Total Ammonia Nitrogen (n = 3)				
0.6 – 1.4	94 – 98	1.27 – 3.58	0.05 – 0.09	Variety of biological nutrient removal (BNR) systems and filtration technologies.
Total Inorganic Nitrogen (n = 129)				
3.0 – 8.0	79 – 92	< 0.10 – 98.40	< 0.01 – 1.85	Activated sludge, lagoons, membrane bioreactors, rotating biological contactors, sequencing batch reactors, and trickling filters.
Total Nitrogen (n = 95)				
2.0 – 16.4	29 – 94	< 0.10 – 22.17	0.02 – 0.51	Variety of BNR, typically paired with filtration or other tertiary treatment systems.

[1] *All costs are presented in 2012 dollars (2012$).*

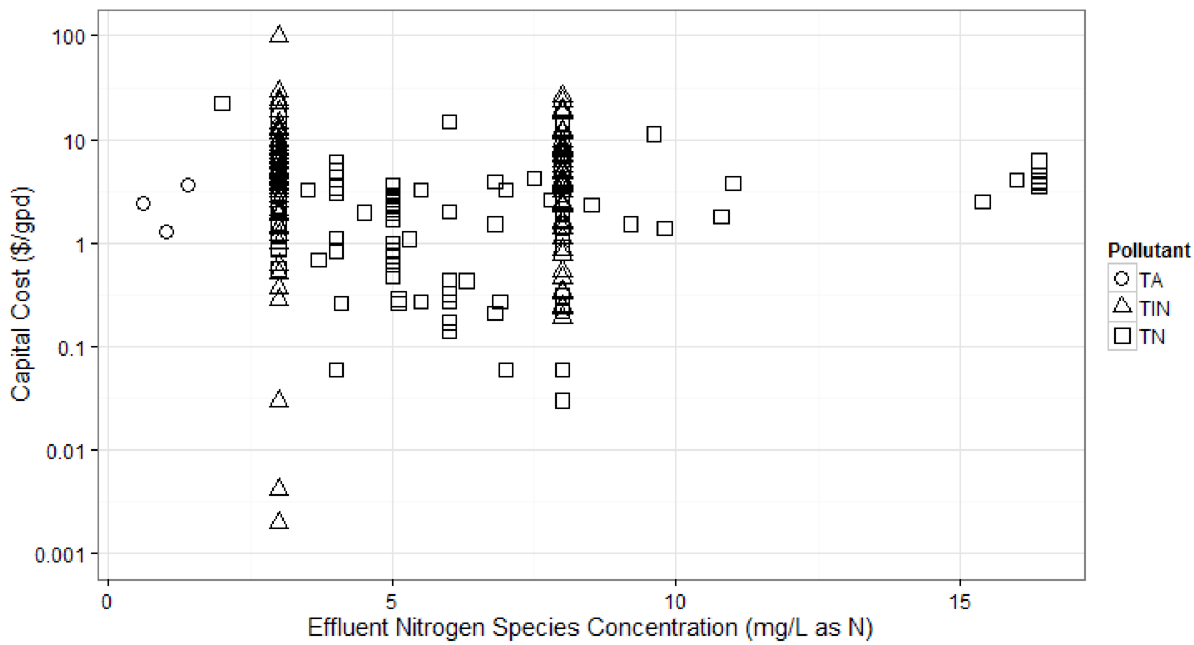


Figure IV-3. Capital cost and nitrogen effluent concentration for municipal WWTPs (2012$).

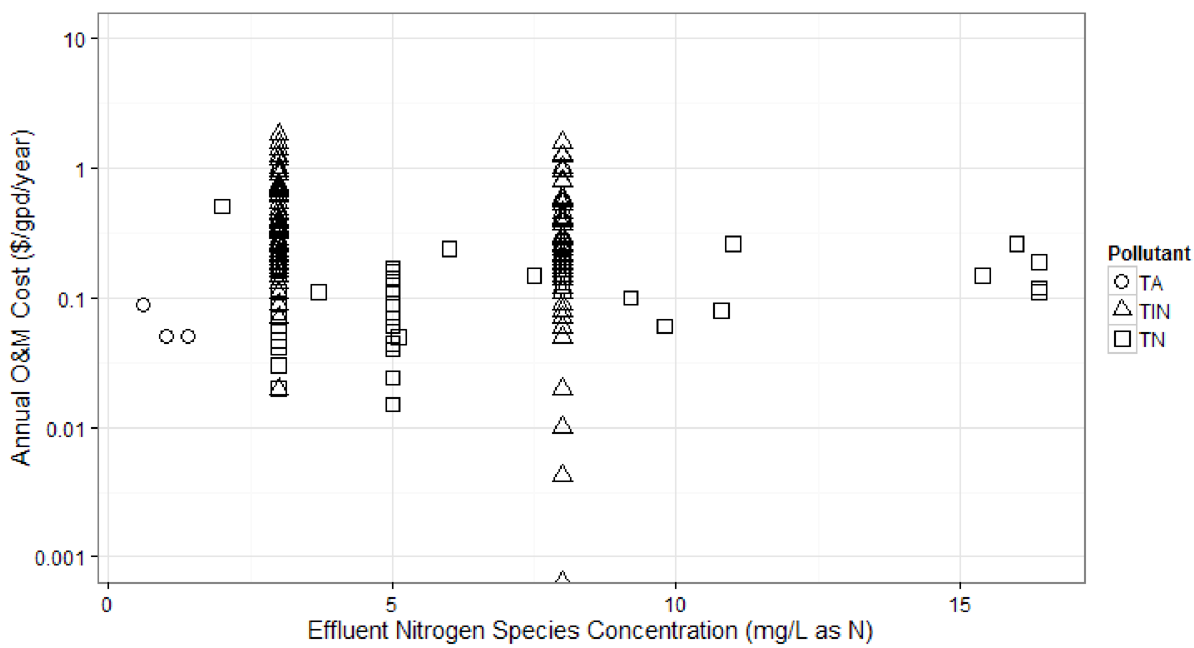


Figure IV-4. Annual O&M cost and nitrogen effluent concentration for municipal WWTPs (2012$).

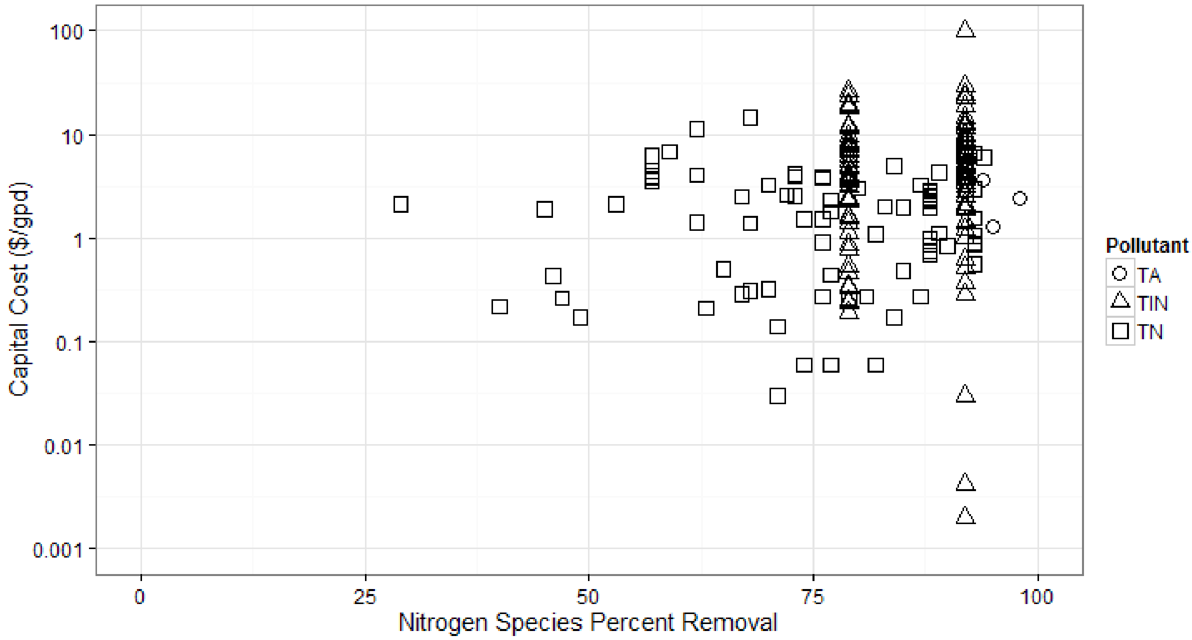


Figure IV-5. Capital cost and nitrogen removal for municipal WWTPs (2012$).

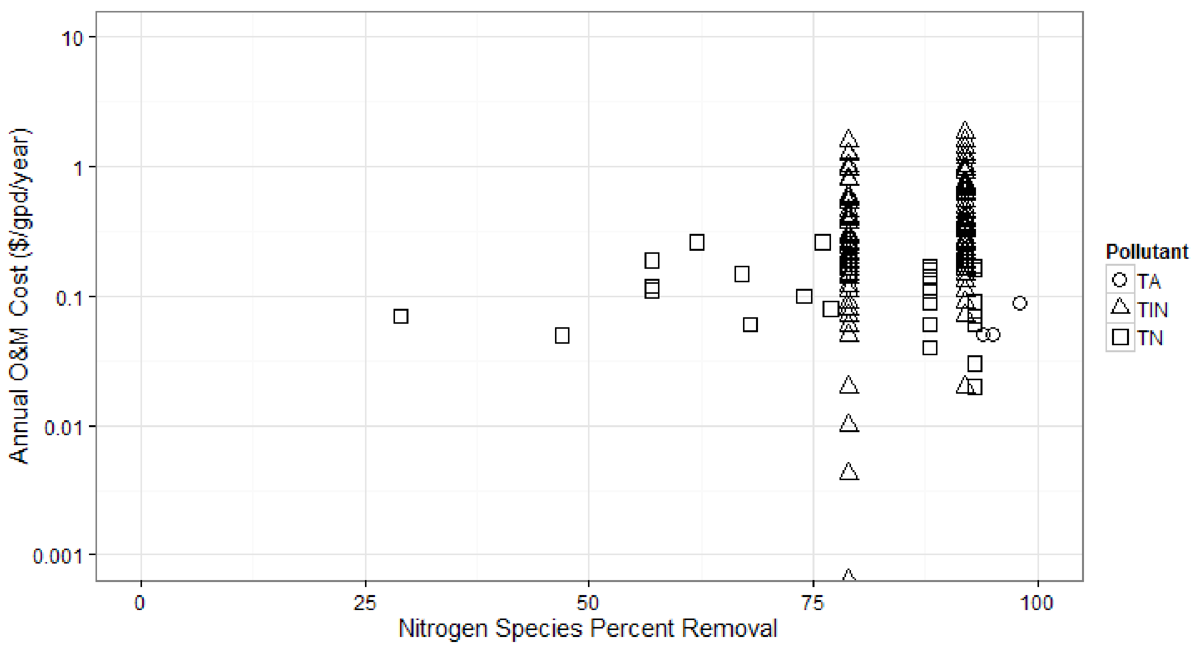
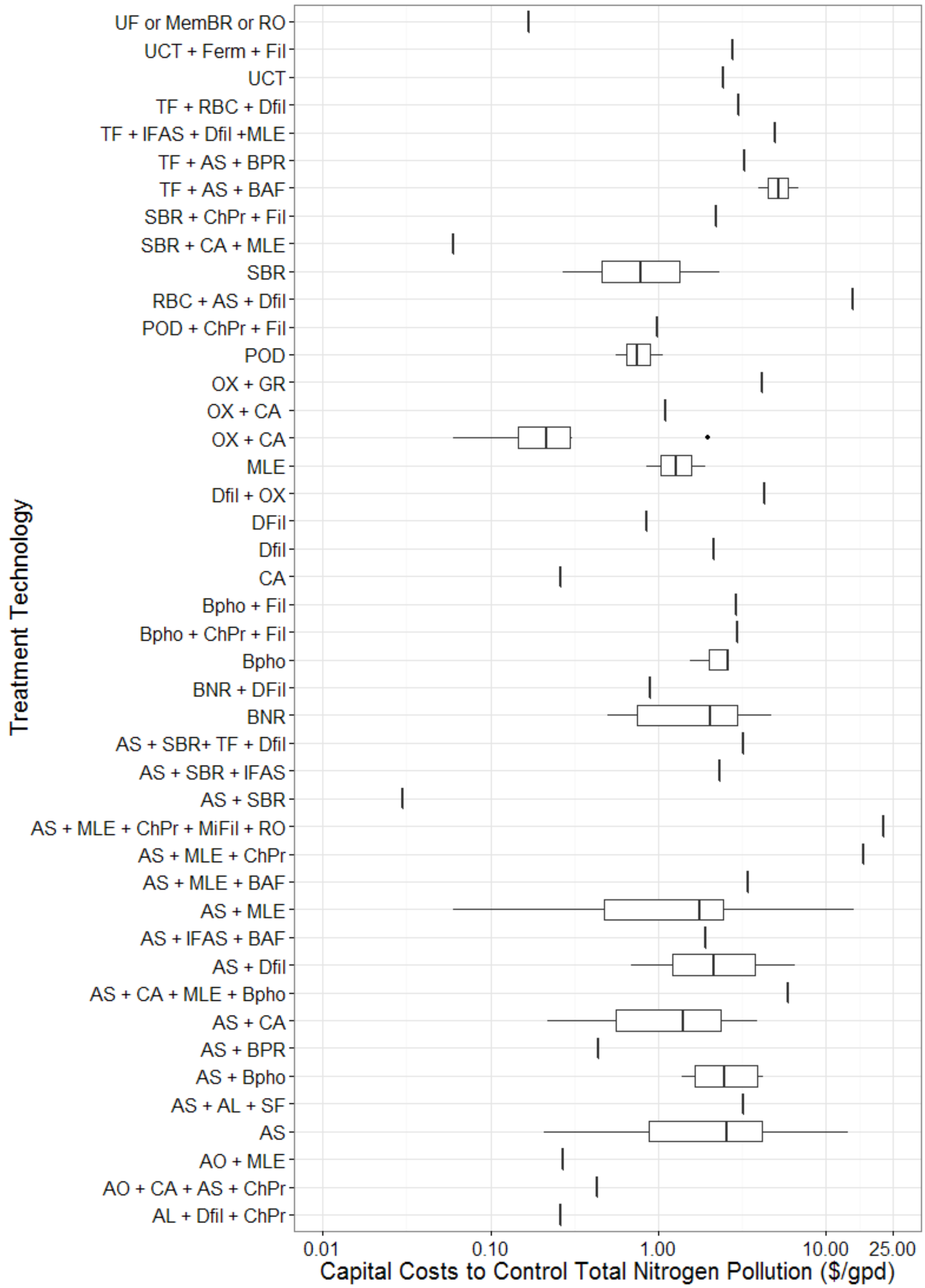


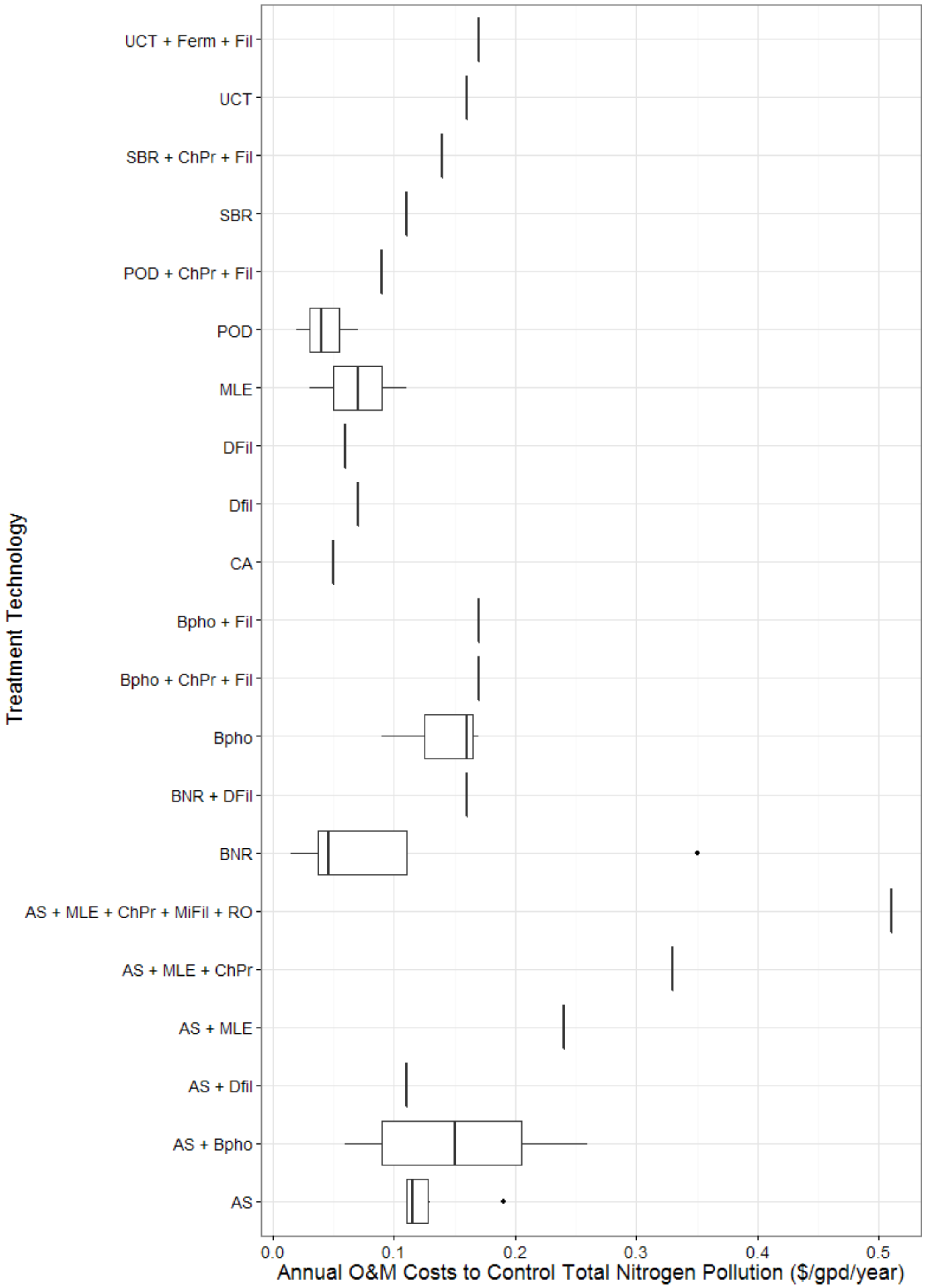
Figure IV-6. Annual O&M cost and nitrogen removal for municipal WWTPs (2012$).

The greatest diversity in treatment technologies for nitrogen was associated with the control of TN (Figures IV-7 and VI-8). The majority of records for TN control include some form of BNR and some form of filtration. Most TN treatment technologies are able to achieve effluent concentrations between 3 and 8 mg/L as N (Figure IV-9).



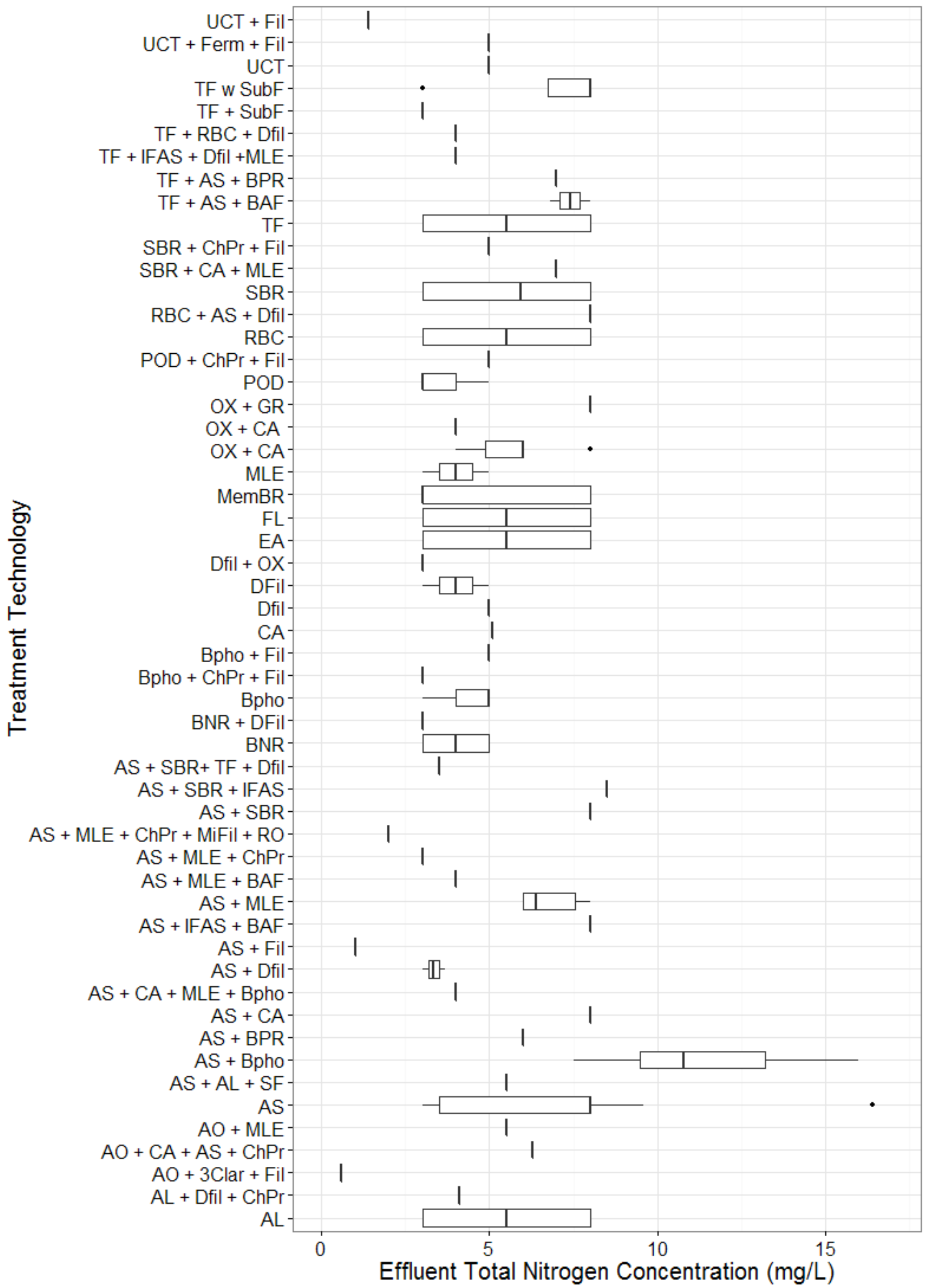
Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-7. Capital costs for TN treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-8. Annual O&M costs for TN treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-9. Effluent TN concentrations for municipal treatment technologies.

Cost and Performance Information – Phosphorus

Cost and performance data were collected and compiled for total phosphorus (TP). Cost and treatment performance ranges for TP are summarized in Table IV-3. Capital costs (Figures IV-10 and IV-12) were typically less than $22/gpd for most technologies, though lagoon-based technologies and oxidation ditches were sometimes reported as more expensive. Annual O&M costs (Figures IV-11 and IV-13) for TP were less than $2/gpd/year and tended to decrease as effluent concentrations increased. New construction costs were frequently higher than costs for improvement of existing plants.

Table IV-3. Total Phosphorus Cost and Treatment Performance for Municipal WWTPs

Effluent Quality (mg/L as P)	Removal Efficiency Range (%)	Capital Cost Range ($/gpd)[1]	Annual O&M Cost Range ($/gpd/year)[1]	Technologies
< 1.0	75 – 99	0.03 – 22.17	<0.01 – 2.33	Chemical precipitation or any of a variety of BNR technologies—BNR frequently used in combination with tertiary filtration, ultrafiltration, and/or reverse osmosis.
< 1.0	81 – 99	0.14 – 98.40	0.04 – 1.85	Lagoons and oxidation ditches capable of meeting this standard but at relatively higher unit costs.
> 1.0	22 – 85	0.05 – 12.82	<0.01 – 1.55	Oxidation ditches, lagoons, and a variety of BNR systems.

[1] *All costs are in 2012$*

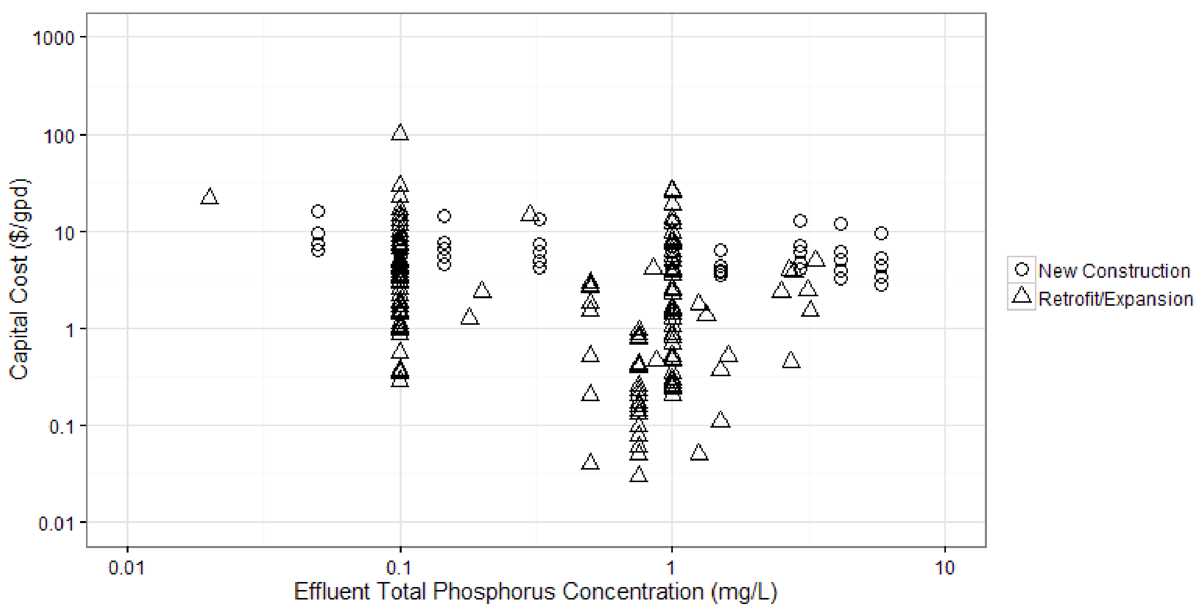


Figure IV-10. Capital cost and phosphorus effluent concentration for municipal WWTPs (2012$).

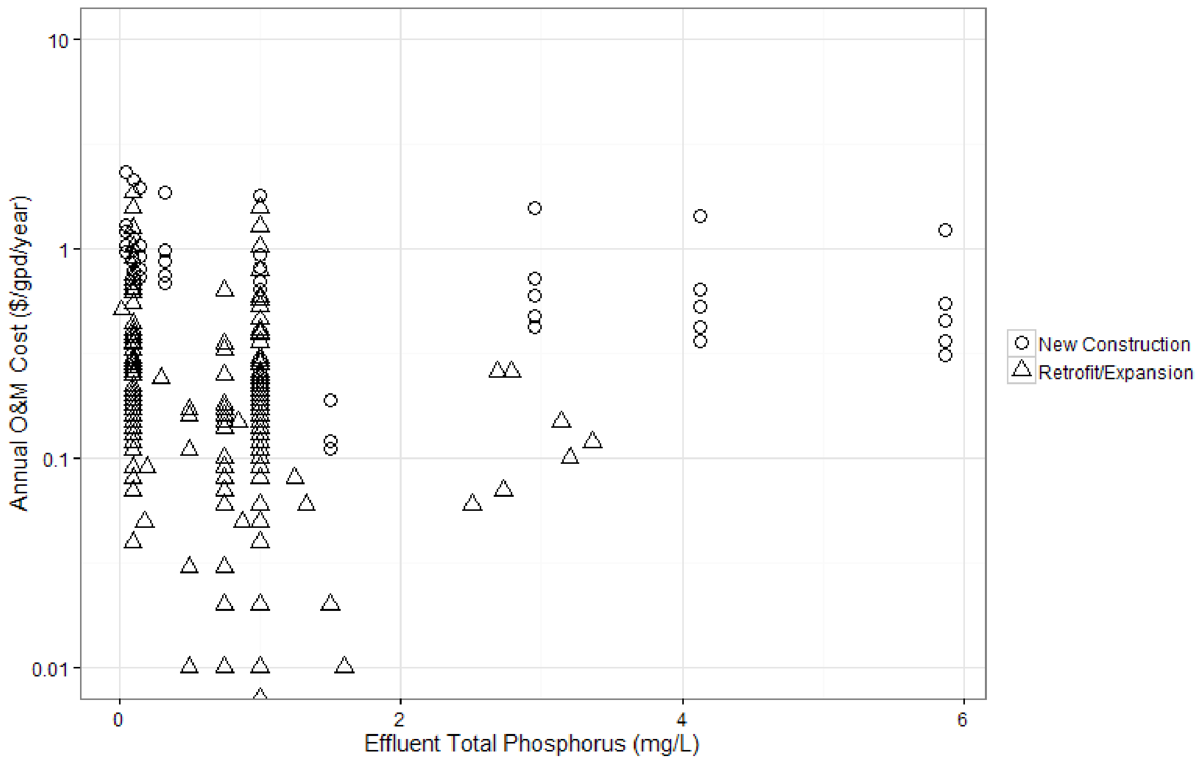


Figure IV-11. Annual O&M cost and phosphorus effluent concentration for municipal WWTPs (2012$).

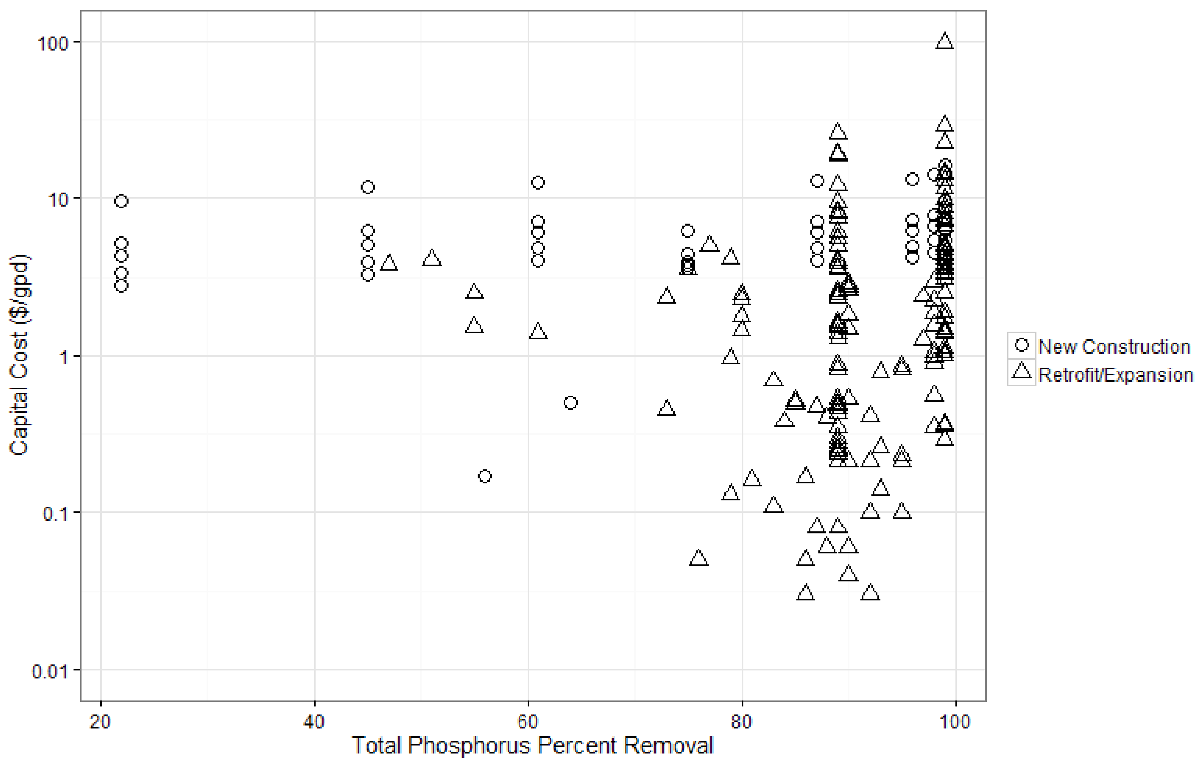


Figure IV-12. Capital cost and TP removal for municipal WWTPs (2012$).

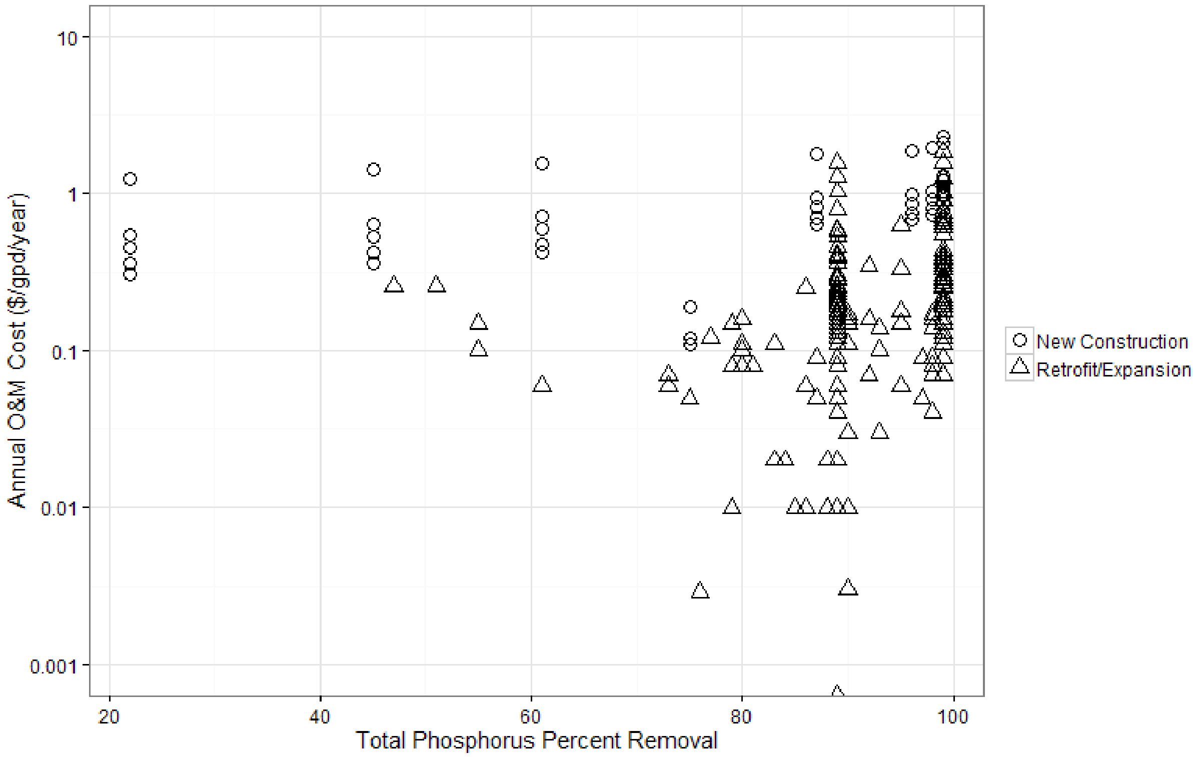
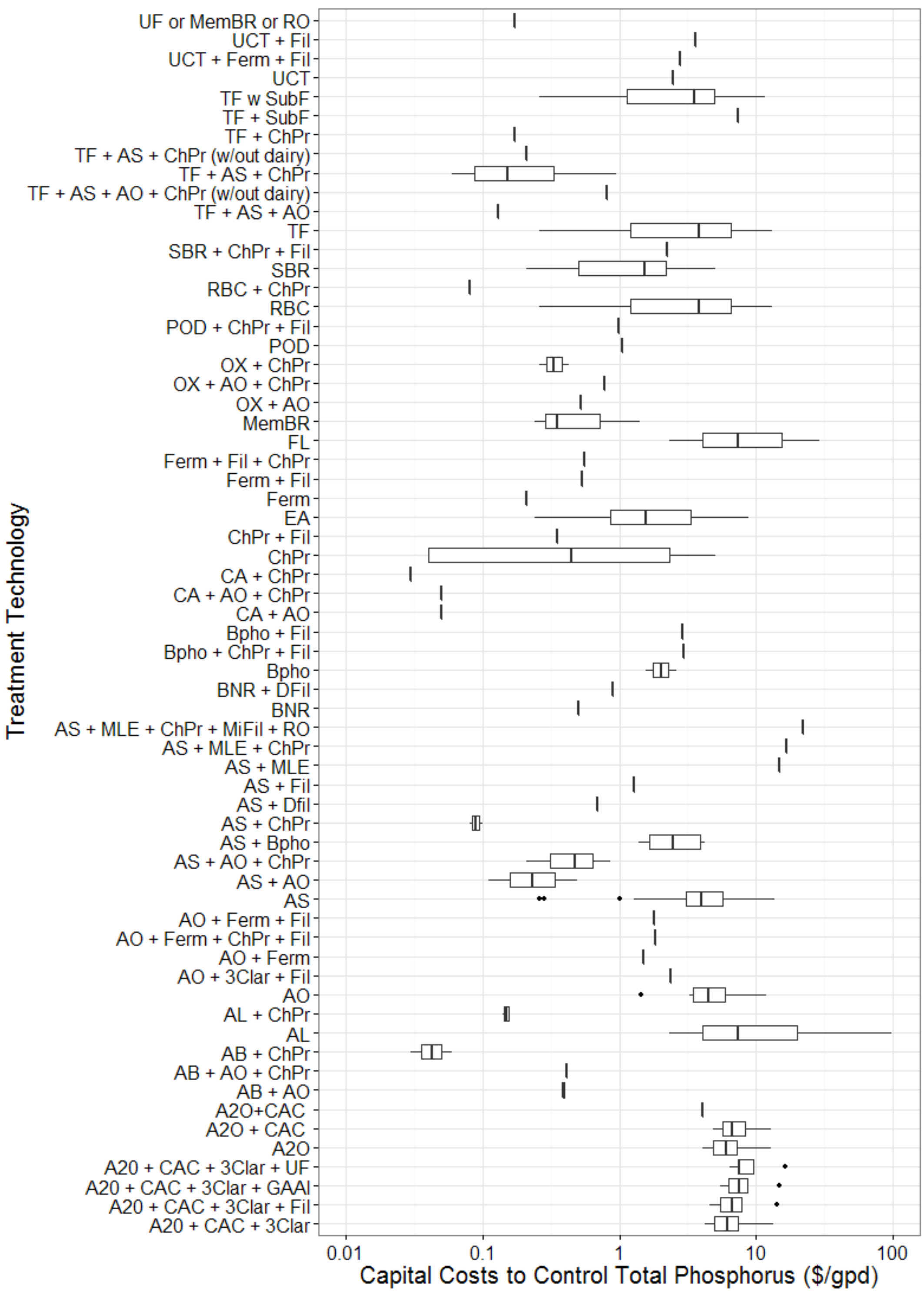


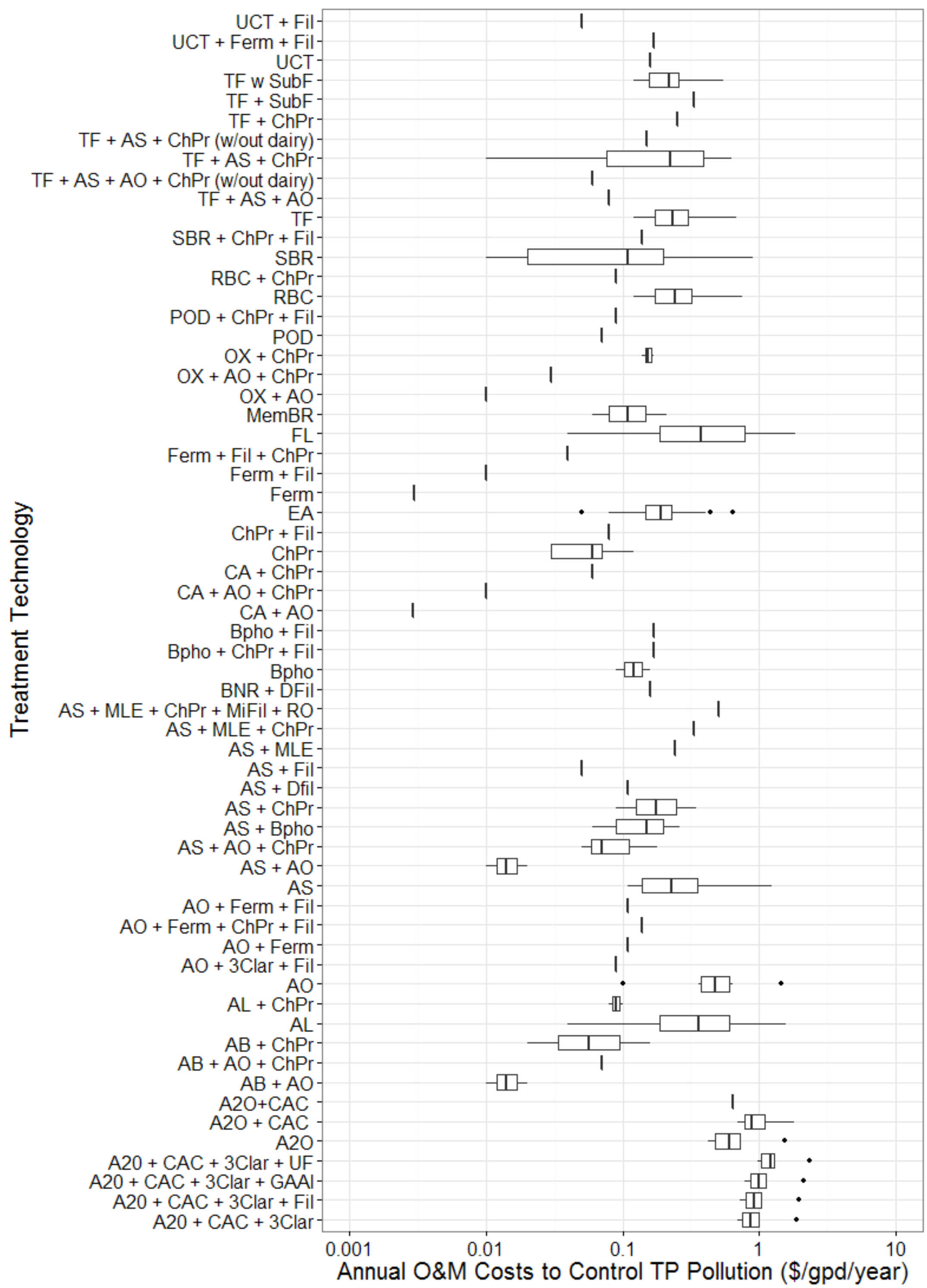
Figure IV-13. Annual O&M cost and TP removal for municipal WWTPs (2012$).

Figures IV-14 and IV-15 display capital costs and annual O&M costs as a function of treatment technology. As shown in Figure IV-16, most of the treatment schemes extracted from the available literature (which involved either technologies operated singly or in combination) can achieve an effluent quality at or below 1 mg/L, and a substantial fraction of the treatment schemes were capable of achieving effluent quality levels at or below 0.5 mg/L (Figure IV-16).



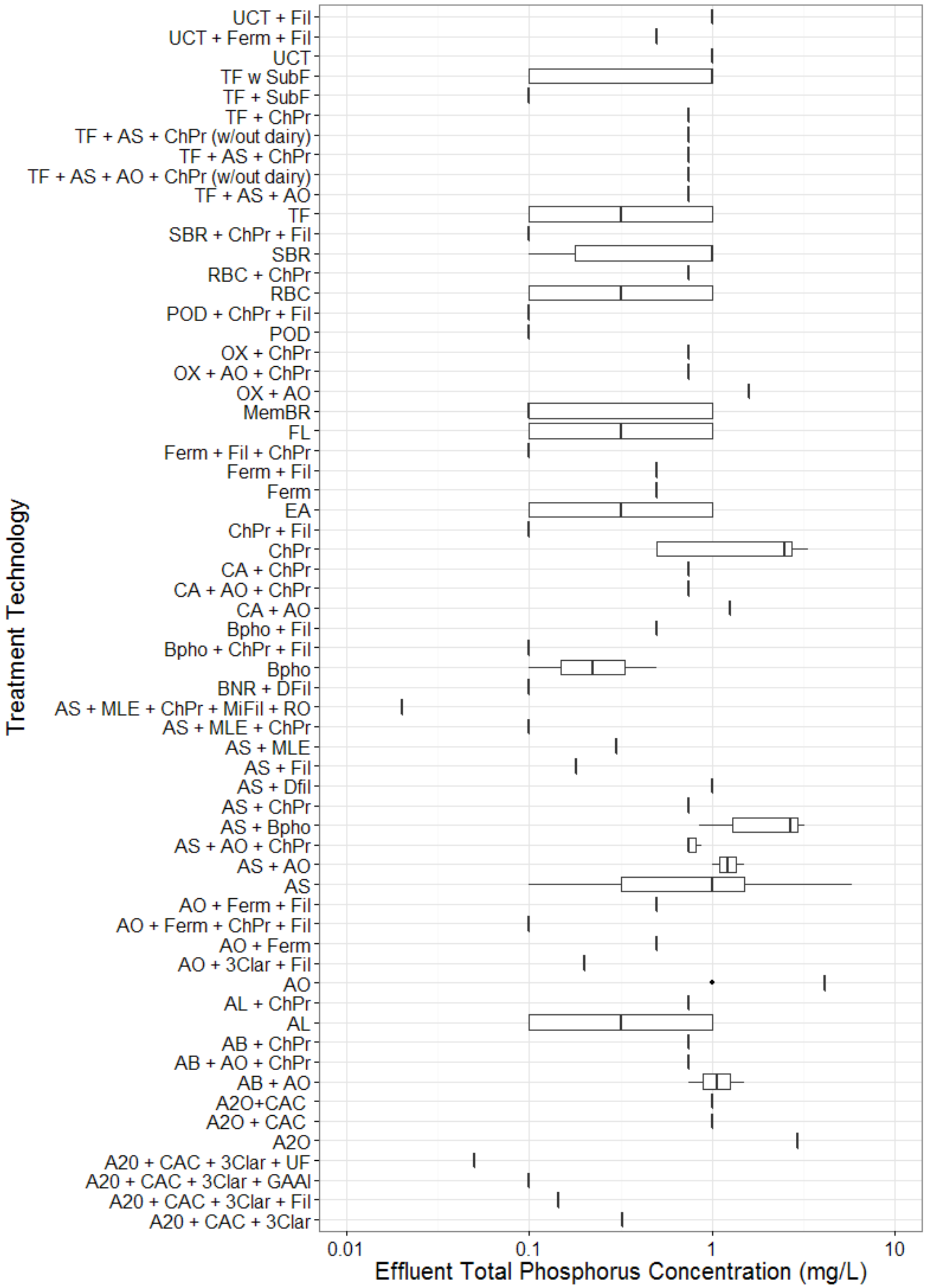
Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-14. Capital costs for TP treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-15. Annual O&M costs for TP treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-16. Effluent TP concentrations for municipal treatment technologies.

Anecdotal Nutrient Cost Data for Municipal Wastewater Treatment Plants

The Maryland Department of the Environment (MDE) maintains estimates of the cost for BNR and enhanced nutrient removal (ENR) at WWTPs in the state. These cost estimates are for completed and planned upgrades using biological and enhanced nutrient removal to ensure compliance with applicable nutrient water quality standards for the Chesapeake Bay. The costs for the completed and planned upgrades have been shared by the state.

In 2004, MDE required all significant municipal WWTPs in the state to upgrade to ENR. In addition, the December 29, 2010 final nutrient TMDL established by the EPA for the Chesapeake Bay allocated waste load allocations for TN and TP for WWTPs in Maryland. The state has revised the cost estimates to reflect the required use of ENR. Because the initial and final TN and TP effluent concentrations (i.e., performance) are not included for each plant, nor are details regarding what the costs represent, these cost estimates were not considered and described earlier in this section. However, these cost data are included in Appendix C as it provides potentially useful information related to the relative cost for upgrades across a wide range of wastewater treatment plant sizes.

IV.A.2. Decentralized Wastewater Treatment Systems

Decentralized wastewater treatment systems provide wastewater treatment for small communities, rural residential areas, and single residences. For purposes of this project, decentralized systems include technologies designated as satellite systems or septic systems, include technologies typically used in municipal wastewater treatment, and that possess treatment capacities of less than 0.1 mgd.

In the course of the literature review, nutrient control cost and treatment performance information were collected. The collected records represent empirical and modeled results for a variety of locations, pollutants, and technologies (Table IV-4).

Table IV-4. Cost and Performance Data for Decentralized Treatment Systems

Category	Number of Records
Total Number of Records	15
Records which Include Data for Nitrogen and/or Phosphorus	
Nitrogen	12
Phosphorus	3
Records for New Plants or Retrofit/Expansion of Existing Plants	
New Construction	0
Retrofit/Expansion	15
Records for Modeled Estimates or for Empirical Data	
Empirical	5
Modeled	10
Regions Where Records are Located	
EPA Region 1	10
EPA Region 2	0
EPA Region 3	2
EPA Region 4	0
EPA Region 5	0
EPA Region 6	3
EPA Region 7	0
EPA Region 8	0
EPA Region 9	0
EPA Region 10	0

Category	Number of Records
Outside United States	0
Location Not Reported [1]	0
Decentralized System Treatment Capacity	
Minimum	0.000175 mgd (175 gpd)
Median	0.0044 mgd (4,400 gpd)
Maximum	0.3 mgd (300,000 gpd)

[1] *A location was registered as "Not Reported" for modeled estimates where the authors did not indicate an assumed location in their methodology. Location information was included for all records associated with empirical results.*

Information regarding decentralized treatment systems was extracted from three sources. As part of a program to reduce nutrient loading to surface waters in the Cape Cod region of Massachusetts, a report by Barnstable County Wastewater Cost Task Force (Barnstable, 2010) contained estimates of costs and TN removal performance for a variety of small systems which scaled from systems designed for single residences up to satellite treatment systems which are appropriate for neighborhoods or clusters of residences.

U.S. EPA (2003) assessed the costs associated with achieving nutrient and sediment reductions in the Chesapeake Bay. In this report, the authors reported cost and performance associated with upgrades to two small treatment systems (an integrated fixed-film activated sludge system and a sequencing batch reactor). The small flows treated by these systems made their inclusion with the decentralized systems more appropriate than inclusion with larger municipal WWTPs would have been.

Keplinger et al. (2003) contains an assessment of the economic and environmental implications of meeting nutrient standards at treatment plants located along the North Bosque River in Texas. In this report, the authors report on results observed at a number of communities, including some that meet criteria for decentralized treatment.

In general, the available information suggests that, on a unit cost basis, greater cost effectiveness can be achieved with larger treatment units (Figures IV-17 and IV-18). Costs for systems with treatment capacities less than or equal to 330 gpd ranged from approximately $13/gpd to $168/gpd for capital costs, and $0.66/gpd/year to $19/gpd/year for annual O&M costs. Cost for units with capacities between 4,000 gpd and 300,000 gpd ranged from approximately $0.16/gpd to $21/gpd for capital costs, and approximately $0.01/gpd/year to $0.67/gpd/year for annual O&M costs. No studies or data were found for capacities between 330 gpd and 4,000 gpd.

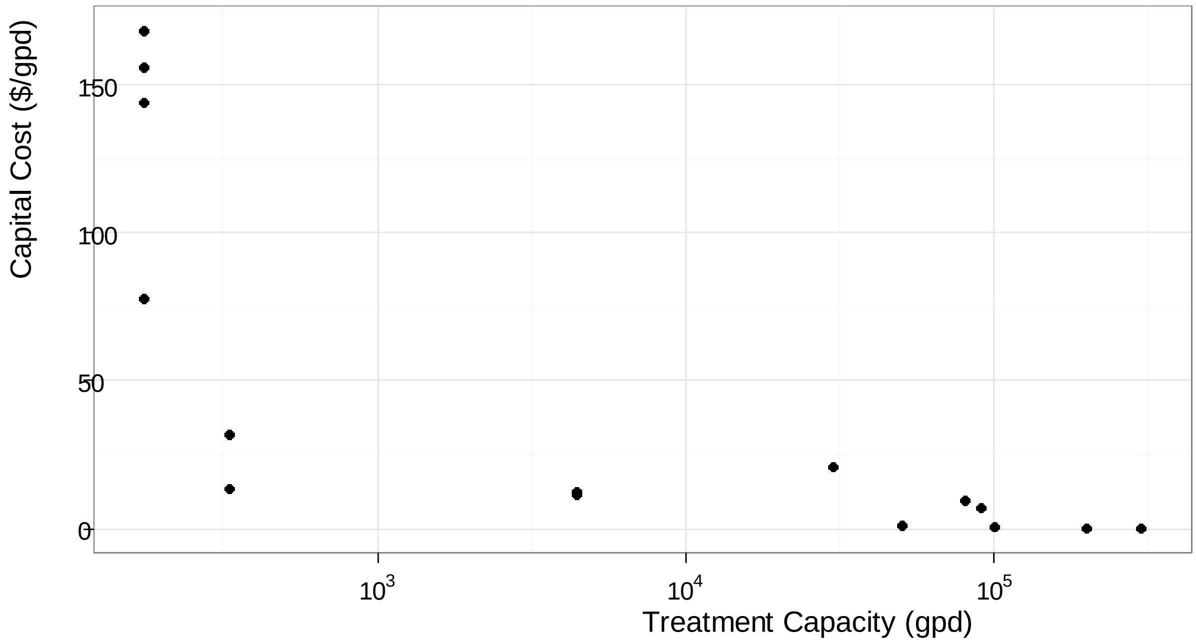


Figure IV-17. Capital costs and treatment capacities for decentralized treatment systems (2012$).

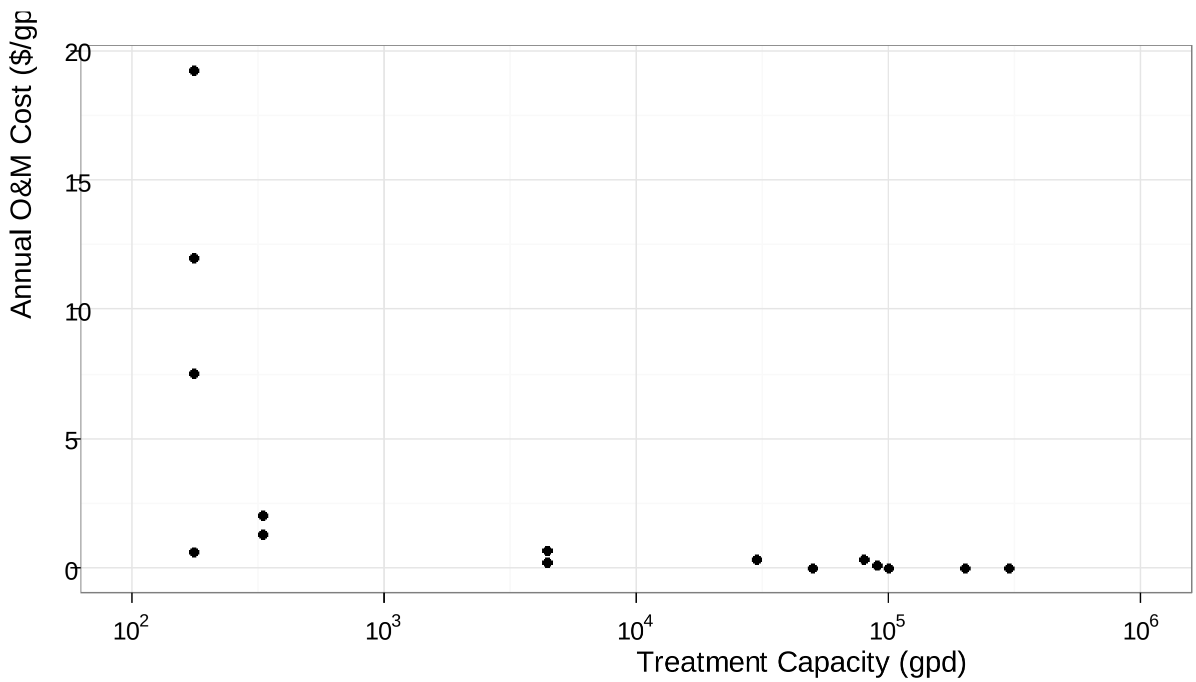


Figure IV-18. Annual O&M costs and treatment capacities for decentralized treatment systems (2012$).

Cost and Performance Information - Nitrogen

The available data suggests that, while larger systems should be able to achieve relatively low TN effluent concentrations, performance of smaller onsite systems may not (Figure IV-19). Capital costs and annual O&M costs as a function of TN effluent quality are shown in Figures IV-20 and IV-21. Costs as a function of TN performance appear to be technologically idiosyncratic, with the lowest costs and best effluent quality delivered by satellite treatment systems and package plants for small communities.

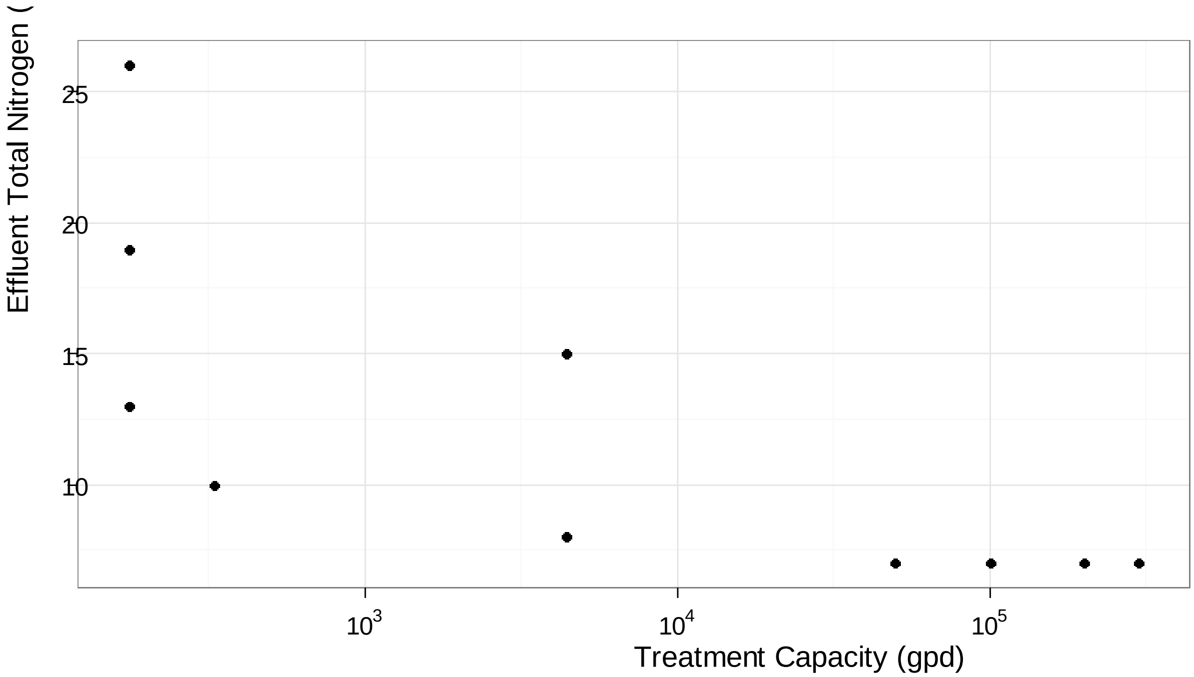


Figure IV-19. TN effluent quality and decentralized treatment system capacity.

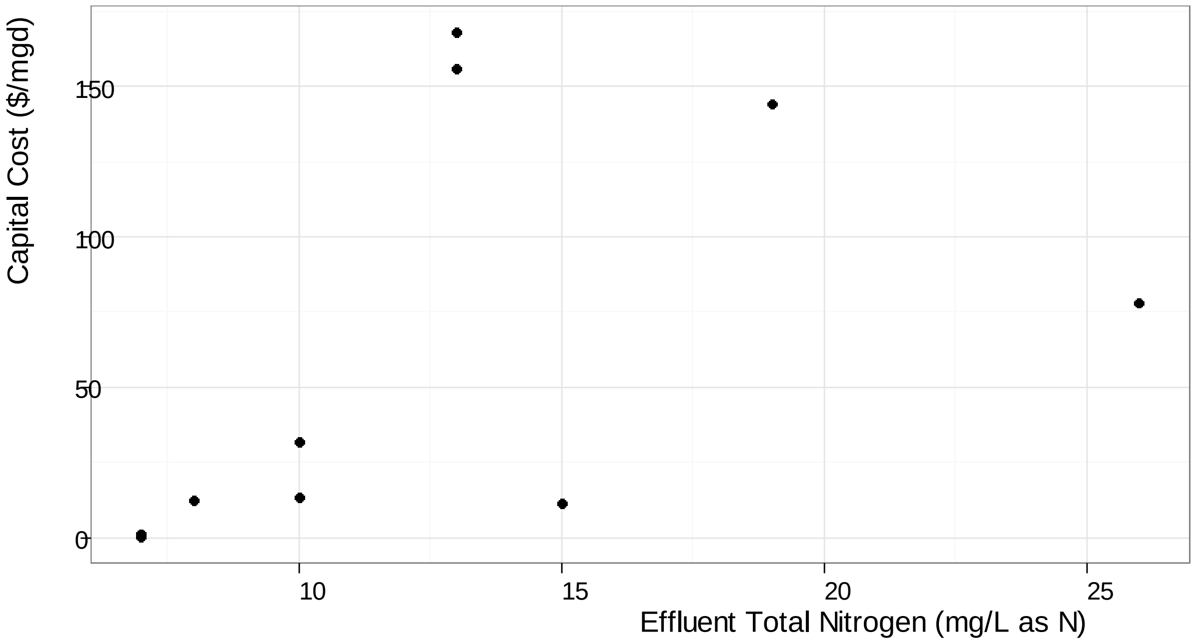


Figure IV-20. Capital costs and TN effluent quality for decentralized systems (2012$).

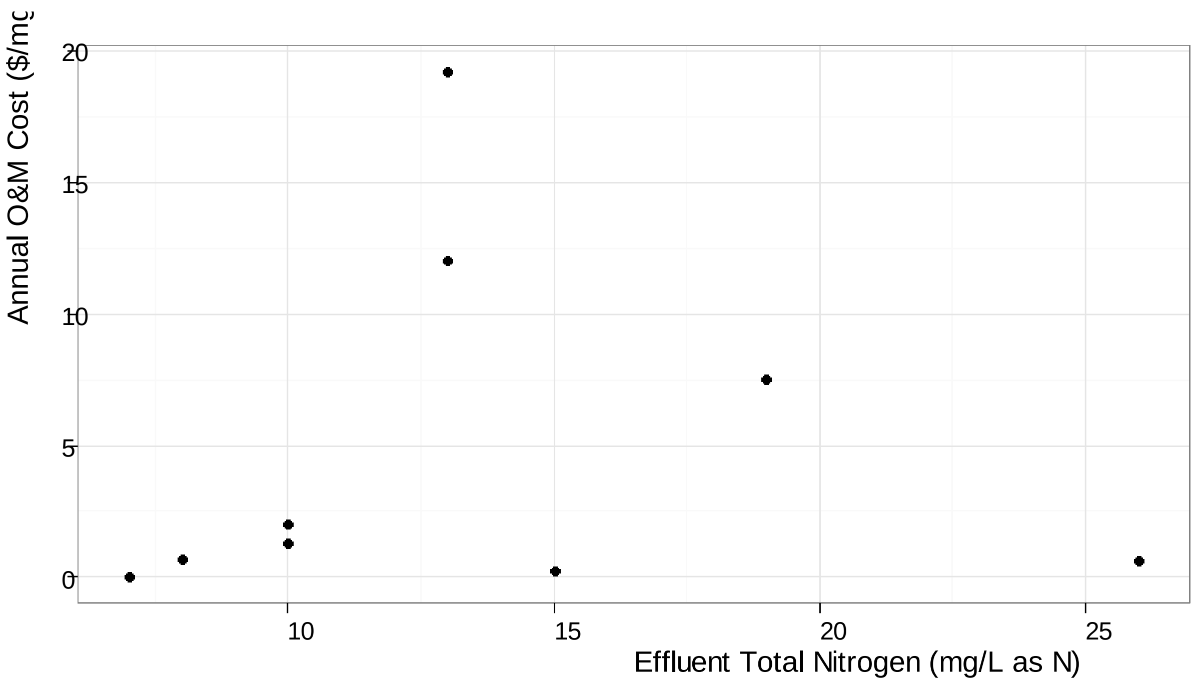


Figure IV-21. Annual O&M costs and TN effluent quality for decentralized systems (2012$).

Cost and Performance Information – Phosphorus

A limited amount of data regarding phosphorus control for decentralized systems was extracted during the literature review. The available information is limited to three data points, all of which are for chemical phosphorus removal systems (0.03 mgd, 0.08 mgd, and 0.09 mgd). These systems were able to achieve TP effluent concentrations between 2.9 and 3.5 mg/L as P. Capital costs ranged from $7.25/gpd (largest system) to $20.85/gpd (smallest system). Annual O&M costs ranged from $0.14/gpd/year (largest system) to $0.36/gpd/year (smallest system).

IV.A.3. Industrial Wastewater Treatment

Industrial wastewater treatment systems provide water pollution control capabilities to industrial point source dischargers. The types of wastewater treated by industrial treatment systems vary according to the type of manufacturing or industrial activity conducted at a given site. Certain types of industrial waste tend to possess greater quantities of nutrients. These may include but are not limited to processors of foodstuffs, beverages, livestock, and agricultural products.

Data extracted during the literature search in accordance with the screening criteria and quality assurance requirements were limited to two available sources (U.S. EPA, 1999; U.S. EPA, 2004) containing cost and treatment information from meat and poultry product processors. This limitation is due to a lack of availability of paired nutrient performance and cost information from other industries. In addition, the available data on meat and poultry processing facilities did not include system treatment capacities or factors which would allow for the calculation of capital and annual O&M unit costs. Therefore, all costs for this section are presented in terms of total dollars per facility and have not been normalized on a unit cost basis (i.e., as $/gpd).

Cost and Performance Information – Nitrogen & Phosphorus

The available information on the treatment of nutrients in wastewater from meat and poultry product processing includes cost and performance data associated with upgrades at existing facilities. These upgrades cover the installation of one of the following treatment options: (1) enhanced aeration, (2) a modified Ludzack-Ettinger (MLE) process, or (3) a MLE process paired with chemical phosphorus removal. Table IV-5 summarizes the results of EPA (2004).

Table IV-5. Effluent Quality, Capital Costs, and Annual Operation and Maintenance Costs for Meat and Poultry Processors[1]

Parameter	Treatment Technology		
	Enhanced Aeration	**Modified MLE Process**	**MLE Process + Chemical Phosphorus Removal**
Number of Records	5	5	10
Total Nitrogen Effluent Quality (mg/L as N)			
Minimum	3.6	34	1.9
Median	3.6	34	23.75
Maximum	4.97	34	34
Total Kjeldahl Nitrogen (TKN) Effluent Quality (mg/L as N)			
Minimum	3.6	3.6	1.34
Median	4.285	3.6	3.4
Maximum	4.97	4.97	4.97
Total Inorganic Nitrogen Effluent Quality (mg/L as N)			
Minimum	Not Available	29.2	0.52

Parameter	Treatment Technology		
	Enhanced Aeration	Modified MLE Process	MLE Process + Chemical Phosphorus Removal
Median		30.6	19.75
Maximum		30.6	30.6
Total Phosphorus Effluent Quality (mg/L as P)			
Minimum	Not Available	8.3	2.3
Median		8.3	5.1
Maximum		8.3	8.3
Capital Cost ($/facility)			
Minimum	105,445	395,069	427,405
Median	388,039	2,160,927	1,081,870
Maximum	1,317,364	3,693,400	5,902,128
Annual Operation and Maintenance Cost ($/facility)			
Minimum	52,020	127,940	139,188
Median	102,633	230,574	719,137
Maximum	390,851	894,177	2,785,164

[1] *Source: U.S. EPA (2004)*

Effluent TN quality for the three treatment strategies varied from 1.4 to 34 mg/L as N. Low TN concentrations were most frequently observed in the effluent of the enhanced aeration units. Effluent TP concentrations ranged from 2.3 to 8.3 mg/L as P with the best performance provided by the MLE process paired with chemical phosphorus removal.

The lowest costs were associated with the enhanced aeration systems. Lacking treatment capacity information to normalize the data with, it is difficult to directly compare the cost of the different systems or determine whether the costs exhibit economies of scale. While the modified Ludzack-Ettinger systems were more expensive than the other two options, it is not clear whether this is a result of treating a larger flow (therefore, necessitating larger systems) or due to relative treatment inefficiencies inherent in these process configurations.

Information for a single facility was extracted from U.S. EPA (1999) for the upgrade of a 1.1 mgd treatment system at an agricultural products processing facility. Post-upgrade the facility possessed an anaerobic lagoon, a modified Ludzack-Ettinger process, a denitrification filter, and a cycled aeration system. It was capable of achieving TN effluent concentrations of 12 mg/L at a unit capital cost of $15.6/gpd.

IV.B. Nonpoint Source Control Costs

Nonpoint sources can be significant contributors to nutrient impairment in surface waters. Nonpoint source pollution originates from rainfall and snowmelt running over and through the ground and entraining pollutants such as nutrients. Eventually the contaminated water migrates to surface waters where the entrained nutrient loadings may contribute to impairment of surface waters. The size and composition of the nutrient loading is, in part, a function of the land use types through which rainfall and snowmelt are deposited, or through which surface water runoff migrates.

Managing nonpoint source pollution plays a vital role in maintaining public health and protecting natural waters. Agricultural and urban residential land uses are critical components of the built environment and are widespread throughout the United States. The availability of adequate land to both produce the food supply and to provide housing is central to the proper functioning of the economy. Agricultural and urban land uses are also potential sources of nonpoint source nutrient pollution, which has the potential to degrade and impair the beneficial uses of surface and ground waters.

This section examines the costs of controlling anthropogenic sources of nonpoint-source nutrient pollution focusing mainly on urban areas. We did not include information in this report at this time on the costs to control nutrients in agricultural areas (e.g., from best management practices) because of the significant breadth and depth of approaches. We intend to focus on those approaches and costs in a supplement or addendum to this report. The literature search also included silviculture and forestry land use types. However, literature meeting the project screening criteria and quality requirements was unavailable for these two land use categories.

IV.B.1. Urban and Residential Runoff

Rainwater and snowmelt falling in urban and other residential areas can be a major nonpoint source contributor to nutrient impairments of surface waters. Rainwater and snowmelt falling on streets, roofs, lawns, and parking lots can capture nutrients. This results in subsequent transport of nutrients to waterways through runoff into storm sewers and waterbodies. Nonpoint source nutrient pollution from urban sources may be controlled through a variety of BMPs. These BMPs include the construction of structures designed to capture and treat the runoff (i.e., structural BMPs). They also include programs and activities (i.e., non-structural BMPs), which communities can implement to decrease the quantity of runoff and/or nutrients deposited in surface waters.

Table IV-6. BMP Cost and Performance for TN and TP Control for Urban and Residential Runoff

Description		Performance	Unit Cost	Reference
Total Nitrogen				
Structural BMPs	Baffle Boxes	15% reduction	$480/acre	SWET (2008)
	Bioretention Units	--	$338-$2,000/lb removed	CWP (2013)
	Bioswales	15-25% reduction	$3,500-$7,000/acre	SWET (2008)
		--	$308/lb removed	CWP (2013)
	Detention Basins	15-20% reduction	$4,400-$8,800/acre	SWET (2008)
		--	$1,100-$4,600/lb removed	CWP (2013)
	Impervious Surfaces	--	$2,428/lb removed	CWP (2013)
	Infiltration Basin	--	$486-$494/lb removed	CWP (2013)
	Media Filtration	--	$975-$1,060/lb removed	CWP (2013)
	Porous Pavement	--	$1,900-$14,000/lb removed	CWP (2013)
Non-Structural BMPs	Illicit Discharge Control Program	--	$8.82-$17.62/lb removed	CWP (2013)
	Lawn Fertilization Programs	15-30% reduction	<$1-$17/acre	SWET (2008)
	Pet Waste Programs	--	$0.43/lb removed	CWP (2013)
	Street Sweeping	--	$3,500-$14,600/lb removed	CWP (2013)
		2% reduction	$22/acre	SWET (2008)
Total Phosphorus				
Structural BMPs	Baffle Boxes	20% reduction	$480/acre	SWET (2008)
	Bioretention Units	--	$338-$2,000/lb removed	CWP (2013)
		72% reduction	$415/m^3 (large units) $939/m^3 (small units)	Weiss, et.al. (2007)

Description		Performance	Unit Cost	Reference
	Bioswales	25-50% reduction	\$3,500-\$7,000/acre	SWET (2008)
		--	\$2,642/lb removed	CWP (2013)
	Chemical Precipitation and Media Filtration	70% reduction	\$3,500/acre	SWET (2008)
	Detention Basins	65-80% reduction	\$4,400-\$8,800/acre	SWET (2008)
		--	\$10,500-\$21,000/lb removed	CWP (2013)
		25% reduction	\$23-\$318/m^3	Weiss, et.al. (2007)
	Impervious Surfaces	--	\$7,322/lb removed	CWP (2013)
	Infiltration Basins	--	\$3,237-\$3,383/lb removed	CWP (2013)
	Infiltration Trenches	65% reduction	\$819-\$1,768/m^3	Weiss, et.al. (2007)
	Media Filtration	--	\$4,500-\$4,900/lb removed	CWP (2013)
		42% reduction	\$235-\$5,000/m^3	Weiss, et.al. (2007)
	Porous Pavement	--	\$12,000-\$70,000/lb removed	CWP (2013)
	Wetlands	46% reduction (Constructed Wetlands)	\$9-\$191/m^3	Weiss, et.al. (2007)
		52% reduction (Wetland Basin)	\$13-\$295/m^3	
Non-Structural BMPs	Illicit Discharge Control Program	--	\$35-\$71/lb removed	CWP (2013)
	Lawn Fertilization Programs	5% reduction	<\$1-\$17/acre	SWET (2008)
	Pet Waste Programs	--	\$3.35/lb removed	CWP (2013)
	Street Sweeping	--	\$1,400-\$2,200/lb removed	CWP (2013)
		15% reduction	\$22/acre	SWET (2008)

IV.C. Data Limitations

As described in the previous sections, there are a number of studies documenting costs and performance information for nutrient control technologies and BMPs across the United States. They demonstrate that strategies exist for controlling nutrient pollution that are applicable to a variety of circumstances and that may vary in terms of their respective cost efficiencies. However, additional data sets and information exist which did not meet the screening acceptability criteria of this literature review effort for various reasons (e.g., lack of availability of both cost and nutrient control performance information was one of the principal barriers to inclusion). As shown in Table IV-6, processes for treatment of industrial waste sources lacked a robust set of information sources meeting screening acceptability criteria. Further, some topics, such as process optimization (see Box 3) where performance at existing WWTPs is improved via optimizing operational control of the treatment systems rather than construction of new unit processes, were not fully represented in the literature but provide promising avenues for cost-effective control of nutrient pollution.

Box 3. Process Optimization

When upgrading an existing plant to meet new nutrient effluent limitations, it is not always necessary to design and construct entirely new treatment units. Plants that possess adequate capacity can consider adopting process optimization measures in order to increase nutrient removal. Process optimization involves making alterations to operationally controlled factors (e.g., aeration control, mean cell retention time) in order to increase the quantity of nitrification or denitrification occurring. An example of this is adding cycled aeration to existing activated sludge processes (see "AS + CA' in Figures IV-7 and IV-9) in order to increase total nitrogen removal. Process optimization measures can often be a more cost-effective means of controlling nutrients as compared to designing and installing new treatment processes.

Table IV-7. Summary of Nutrient Control Cost Documentation

Control	Number of Studies	Locations
Municipal Wastewater Treatment Plants	11	CT, DC, FL, IL, MD, MN, MT, NC, NV, NY, PA, TX, VA, WA, national, and Spain
Decentralized Wastewater Treatment Systems	3	DC, MA, MD, PA, TX, and VA
Industrial Wastewater Treatment	2	Not Available
Urban and Residential Runoff	3	FL, IA, IL, IN, ME, MI, MN, NJ, OH, PA, VA, WI, and national

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Appendix A: Additional Evidence Of The Costs Of Nutrient Pollution

The studies described in Section III.A.1 through Section III.A.4 meet the evaluation criteria shown in Box 2 in Section III.A Additional studies may provide supporting information on the adverse impacts of anthropogenic nutrient loading. These include both anecdotal evidence of adverse economic impacts from nutrient pollution, such as newspaper accounts of algal bloom events, and additional studies that use broader assumptions or methodologies than those meeting the criteria. This appendix provides more detail on the anecdotal evidence and additional studies.

Table A-1 and Table A-2 provide anecdotal evidence and summarize additional studies of the local economic impacts and increased costs associated with nutrient pollution. Table A-3 provides a summary of anecdotal mitigation costs (in the form of restoration and water quality improvement projects designed to meet phosphorus load reductions under Florida's Upper Ocklawaha River Basin TMDL (UOBWG, 2007)). Note that this is not a comprehensive listing, and new information is continually emerging. The dollar values are in the original reported year dollars.

Anecdotal Evidence—Many HAB events and excessive nutrient concentrations have caused economic impacts that receive the attention of local news outlets. Table A-1 in Appendix A provides details of anecdotal evidence of impacts in the commercial fishing, tourism and recreation, and real estate industries. For example, liver toxins produced by algae near beaches in Buckeye Lake, Ohio have necessitated warnings against swimming for three summers, resulting in revenue losses to surrounding tourism businesses (Hunt 2013). According to The Columbus Dispatch (Hunt 2013), the Ohio EPA has spent more than $700,000 on identifying sources of excessive phosphorus and reducing in-lake algae. In Northwest Creek, Maryland, HABs have necessitated the closures of beaches, cancelation of planned events, 18 fish kills, and declines in property values. The Baltimore Sun (Wheeler 2013) reports that plans to restore the creek would cost approximately $1 million.

Additional Studies—Table A-2 provides details of studies that do not meet the economic impact evaluation criteria but nonetheless provide quantitative estimates of the economic impact of nutrient pollution. In some cases, the impacts documented in these studies were not fully attributable to anthropogenic nutrient pollution (i.e., algal blooms and other manifestations were attributable to natural causes) or used modeling to estimate the impacts of prospective events rather than past events. However, these studies still provide evidence of the magnitude of economic impacts that anthropogenic nutrient pollution can inflict.

For example, Athearn (2008) used regression analysis as well as input-output modeling to estimate the economic impacts of a 2005 red tide event on the commercial fishing industry in Maine. The author estimated that this event resulted in $6 million in losses to soft shell clam, mahogany quahog, and mussel harvesters, as well as $14.8 million in lost sales and $7.9 million in income (including indirect and induced impacts; 2005$). However, some of these impacts may also have been attributable to flooding and other concurrent events.

Additionally, some studies compile estimates of the economic impacts of nutrient pollution at the national level across multiple sectors. For example, Anderson et al. (2000) estimated the potential annual impacts of HABs nationally by compiling estimates in public health, fisheries, recreation and tourism, and monitoring and management. The authors note that their results are underestimates due to additional unquantified categories of impacts, but estimated that (2000$):

- Shellfish and ciguatera fish poisoning[19] resulted in $33.9 million to $81.6 million in public health expenditures annually.
- Wild harvest and aquaculture losses associated with shellfish poisoning, ciguatera, and brown tides resulted in $18.5 million to $24.9 million in annual commercial fishing losses.
- Tourism industries in North Carolina, Oregon, and Washington lost up to $29.3 million annually.
- Monitoring and management programs (such as routine shellfish toxin monitoring) distributed among 12 states cost $2.0 million to $2.1 million annually.

Dodds et al. (2009) also developed national level estimates of the impacts of nutrient pollution. They compared nutrient concentrations for EPA ecoregions to reference conditions to identify areas potentially impacted by nutrient pollution; then estimated annual impacts to recreation, real estate, spending on threatened and endangered species recovery, and drinking water. Their results for each sector were (2001$):

- $189 million–$589 million in annual fishing expenditure losses and $182 million–$567 million in annual boating expenditure losses (based on lake area closures and expenditures)
- $0.3 billion–$2.8 billion in annual property value losses (depending on the assumed land availability)
- $44 million in spending to develop conservation plans for 60 species impacted by eutrophication
- $813 million in annual expenditures on bottled water due to taste and odor issues in public water supplies attributable to eutrophication.

In the following discussion, supplementary information on drinking water treatment costs and mitigation costs are presented.

Anecdotal Evidence—A large body of anecdotal evidence (such as newspaper articles) documents the need for increased expenditures on drinking water treatment as a result of algal blooms. Some of this evidence is shown in Table A-1. In some cases, health hazards resulting from HABs have caused drinking water treatment plants to go offline altogether, as happened in Carroll Township on Lake Erie, a facility serving 2,000 residents (Henry, 2013). Also on Lake Erie, the City of Toledo has spent more than $3,000 to $4,000 per day on carbon activated filtration during bloom events (Lake Erie Improvement Association 2012). In the summer of 2014, about 500,000 residents in Toledo lost access to drinking water due to a large algal bloom that affected the city's treatment facilities.

KDHE (2011) reports that the City of Wichita installed an $8.5 million ozone facility at Cheney Reservoir to control taste and odor problems, and that there have been incidences throughout the

[19] Ciguatera fish poisoning (or ciguatera) is an illness caused by eating fish that contain toxins produced by a marine microalga called *Gambierdiscus toxicus*. People who have ciguatera may experience nausea, vomiting, and neurologic symptoms, such as tingling fingers and toes.

state of drinking water treatment plants being forced to shut down during moderate to severe algal blooms due to the inability to adequately treat the source water.

With regard to mitigation, UOBWG (2007) presents costs for ongoing or completed mitigation projects that the basin workgroup identified as necessary to meet phosphorus load reductions under Florida's Upper Ocklawaha River Basin TMDL. Mitigation techniques include alum treatment, dredging, fish removal, and modification of hydrodynamics. The workgroup identified 14 restoration and water quality improvement projects totaling approximately $162 million. These projects are summarized in Table A-3.

Additional Studies—Table A-2 provides details of studies that do not meet the evaluation criteria but nonetheless provide quantitative estimates of the increased drinking water treatment costs associated with nutrient pollution. In some cases, the additional needs for treatment were not fully attributable to anthropogenic nutrient pollution (i.e., algal blooms and other manifestations were attributable to natural causes) or the technologies evaluated are outdated. However, these studies still provide evidence of the scale of increased drinking water treatment costs associated with anthropogenic nutrient pollution.

Table A-1. Summary of Anecdotal Evidence of the Costs of Nutrient Pollution

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Tourism and Recreation					
Hunt (2013)	Newspaper article	Algal blooms	OH	Buckeye Lake	Due to the presence of a liver toxin produced by algae near beaches, state park officials have posted warnings for swimmers along the beaches of Buckeye Lake in Fairfield, Licking, and Perry Counties for the last 3 summers, and revenues have declined. The toxic algae is attributed to excess phosphorus loading from manure, sewage, and fertilizers. Since 2011, the Ohio Environmental Protection Agency has spent more than $700,000 on efforts to identify sources of phosphorus loading and to reduce algae at Buckeye Lake.
HARRNESS (2005)	Strategy document	Algal blooms	WA and OR	Recreational razor clam fishery closed due to domoic acid (from harmful algae) contamination throughout WA and OR coastal communities	Estimated reductions in recreational spending of $10 million to $12 million in small coastal communities; loss of subsistence fishing for Native American coastal tribes.

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Times Standard (2013)	Newspaper article	Algal blooms	CA	Reaches of the Klamath River including the Copco and Iron Gate Reservoirs	Blue-green algae blooms have necessitated warnings against human and animal contact with and consumption of water in the river due to health concerns. Economic impacts are not quantified but could include decreased tourism and recreational revenues.
The Associated Press (2013)	Newspaper article	Algal blooms	KY	Four Kentucky lakes: Rough River, Barren River, Taylorsville, and Nolin.	HABs have been detected at 4 Kentucky lakes during the summer of 2013. Collectively, these lakes receive approximately 5 million visitors per year, and a lake manager reports that some visitors have cancelled campground reservations.
Wheeler (2013)	Newspaper article	Algal blooms	MD	Northwest Creek	Harmful algal blooms have necessitated warnings against swimming and beach closures, with scheduled Girl Scout camps being closed, and property values declining; there have been 18 fish kills in Northwest Creek since 1986. Plans to restore the creek are estimated to cost $1 million.
		Commercial Fishing			
Glass (2003)	Workshop presentation	Algal blooms	TX	Freshwaters in Texas impacted by golden algae (*Prymnesium parvum*).	Conservative estimate of the number of fish killed is 17.5 million; estimated value of fish killed is more than $7 million. Unknown indirect losses to local tourism, sport fishing, and state revenues.
		Property Values			
Wheeler (2013)	Newspaper article	Algal blooms	MD	Northwest Creek	Harmful algal blooms have necessitated warnings against swimming and beach closures, with scheduled Girl Scout camps being closed, and property values declining; there have been 18 fish kills in Northwest Creek since 1986. Plans to restore the creek are estimated to cost $1 million.
		Drinking Water Treatment			
Lollar (2008)	Newspaper article	Algal blooms	FL	Caloosahatchee River	Harmful algal blooms caused the closure of a water treatment facility.

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Des Moines Register (2013)	Newspaper article	Nitrate concentrations	IA	Des Moines River and Raccoon River	Health-threatening levels of nitrates in surface waters used for drinking water necessitated the use of a nitrate removal plant, which has not been needed since 2007 (the plant cost $4 million to construct in 1992). The plant costs about $7,000 per day to run, although it is not clear if those are operating costs at full capacity or at current capacity (the plant is only using 4 of the 8 treatment cells).
Henry (2013)	Newspaper article	Algal blooms	OH	Lake Erie	Extremely high levels of toxic algae in the lake knocked the water treatment plant offline (which serves 2,000 residents of Carroll Township).
Lake Erie Improvement Association (2012)	Association plan documentation	Algal blooms	OH	Lake Erie	The City of Toledo spent $3,000 to $4,000 per day on carbon activated filtration during algal blooms, plus additional costs to treat water with potassium permanganate.
City News Service (2011)	Newspaper article	Algal blooms	CA	Drinking water in eastern Los Angeles County and parts of Orange County, western San Bernardino County, and southwest Riverside County	Algal blooms caused taste and odor issues for drinking water in Los Angeles County and parts of Orange County, San Bernardino County, and Riverside County. Utilities have applied copper sulfate to control the bloom, but the taste and odor issues persisted, affecting approximately 7 million people in the area.
KDHE (2011)	Report	Algal blooms	KS	Reservoirs throughout Kansas impacted by excess algae	The city of Wichita constructed an $8.5 million ozone facility at Cheney Reservoir to control taste and odor problems. In Kansas, there have been a few incidences of drinking water treatment plants being forced to shut down during moderate to severe algal blooms due to the inability to adequately treat the source water.

Table A-2. Summary of Additional Studies of the Costs of Nutrient Pollution

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
National Aggregate				
Anderson, et al. (2000)	Algal blooms	National	Coastal waters throughout the U.S.	• Annual economic impacts $33.9 million–$81.6 million (2000$). • Public health (shellfish and ciguatera poisoning) $18.5million–$24.9 million. • Commercial fishery (wild harvest and aquaculture losses associated with shellfish poisoning, ciguatera, and brown tides) $13.4 million–$25.3million. • Recreation/tourism (impacts documented in NC, OR, and WA in various years) $0–$29.3 million. • Monitoring/management (cost of routine shellfish toxin monitoring programs, plankton monitoring, and other activities in 12 states) $2.0 million–$2.1 million.
Dodds, et al. (2009)	Eutrophication	National	Freshwaters throughout the United States	• Fishing and boating trip-related expenditure annual losses of $189 million–$589 million and $182 million–$567 million, respectively (2001$). • Property value annual losses (scaled over 50 years) of $0.3 billion, $1.4 billion, and $2.8 billion for the low (5% private), intermediate (25% private), and high (50% private) assumed land availabilities, respectively. • Aquatic biodiversity impacts of $44 million per year to develop 60 plans for the species that are at least partially imperiled due to eutrophication. • Drinking water impacts of $813 million per year for bottled water because of taste and odor problems potentially linked to eutrophication (2001 dollars).
Tourism and Recreation				
Morgan and Larkin (2006)	Red tide	FL	Coastal waters	Presence of red tide on a given day reduces restaurant sales by $616 (2005 dollars) (5% to 14% of daily sales for the 3 restaurants evaluated); however, impacts may also be caused at least partially by natural drivers, and authors note that the model is likely to be mis-specified.
Adams, et al. (2002)	Red tide	FL	Ft Walton Beach and Destin areas	In one zip code, the monthly losses associated with a red tide event are $2.23 million for restaurants and $2.29 million for hotels; however, impacts may also be caused at least partially by natural drivers.

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Commercial Fishing				
Athearn (2008)	Red tide	ME	Coastal fisheries	$6 million in losses for harvesters of soft-shell clams, mahogany quahogs, and mussels, including indirect and induced impacts $14.8 million lost in sales and $7.9 million in lost income (2005$); however, some damages were attributable to sources besides or in addition to anthropogenic nutrient pollution, such as flooding.
Gorte (1994)	Algal blooms	FL	Florida Bay in Monroe County	Losses of 500 jobs and $32 million in annual personal income due to decline in pink shrimp harvest between 1986 and 1994. Unable to attribute commercial fishing revenue changes to nutrient enrichment since revenues went down statewide during the same period due to a weak economy.
Huang, et al. (2012)	Hypoxia	NC	Coastal waters	Between 1999 and 2005, the average number of hypoxic days (61) led to a $261,372 welfare loss (2005$).
Property Values				
Carey and Leftwich (2007)	Algal blooms	SC	Greenwood County shore of Lake Greenwood	Chl-a concentrations and the presence of algal blooms (as indicated by a dummy variable for year of bloom and immediately after) are both insignificantly related to the house price. Primary model only uses a dummy variable for whether the sale occurred between July 1999 and July 2001 (the period of the bloom and immediately after); however, it is unclear whether there were nutrient or algal bloom problems in any other years besides 1999 through 2001.
Steinnes (1992)	Reduced clarity	MN	53 lakes	An additional foot of clarity raises the value of a lakefront lot by between $206 and $240; however, clarity problems are not explicitly tied to nutrient pollution.
Young (1984)	Algal blooms	VT	Lake Champaign	The value of properties is depressed by 20% ($4,500 on average) when the properties are located on an area of the lake that has degraded water quality (St. Albans Bay). Water quality variable was a one-time ranking of water quality by 30 individuals at 10 locations throughout the study area, while property data covered 6 years of sales.
van Beukering and Cesar (2004)	Algal blooms	HI	Coral reefs off the coast of Maui (Kihei area)	Reducing nutrients results in a $30 million (approximate) increase in property values of houses, hotels, and condominiums that are associated with coral reefs.
Cesar, et al. (2002)	Algal blooms	HI	Coastal waters	Units in algae zones were about 43% as valuable as units in algae-free areas. Extrapolating to all 754 "algae zone" units yields depreciation value of $9.4 million per year in lost value. Conclusions rely heavily on public perception and not statistical or data-driven analysis.

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Drinking Water Treatment				
Ribaudo, et al. (2011)	Nutrient concentrations	National	U.S. drinking water supplies	Nitrate removal from U.S. drinking water supplies costs more than $4.8 billion per year; however, the cost estimates are based on 1996 technologies and as such may not be applicable.
Caron et al. (2010)	Red tide	CA	Pacific Ocean	Harmful algal blooms (red tide in this case) can cause operational issues at desalination plants, including increased chemical consumption, increased membrane fouling rates, and in some cases plant shut-downs; however, these events are not necessarily attributable to anthropogenic nutrient pollution.
Oneby and Bollyky (2006)	Algal blooms (turbidity)	KS	Cheney Reservoir outside of Wichita, Kansas	Cost to install ozonation system prior to drinking water treatment plant was $8.5 million (completed in 2005). Study does not provide description of what project costs entailed or source/citation of costs.

Table A-3. Summary of Anecdotal Mitigation Costs in Florida

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
ABC01 - Nutrient Reduction Facility	Apopka-Beauclair Canal/CC Ranch / Water in Apopka-Beauclair Canal treated offline with alum. Removes TP from Lake Apopka discharge. Reduces loading from Lake Apopka to Lake Beauclair and Apopka-Beauclair Canal.	5,000	2835A; 2834C	LCWA / LCWA; Legislature / SJRWMD/DEP	$5,200,000
BCL02 - Suction dredging of western Lake Beauclair	Western end of Lake Beauclair / Suction dredging to remove 1 million cubic yards of sediment in western end of Lake Beauclair.	Unknown	2834C	FWC/LCWA/SJRWMD / cost share/ --	$12,000,000
BCL03 - Gizzard shad harvest	Lake Beauclair in-lake removal of fish / Harvest of gizzard shad by commercial fishermen. Removal of fish removes nutrients from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension—total suspended solids (TSS). Stabilizes bottom to reduce TSS.	Unknown	2834C	SJRWMD / SJRWMD Ad valorem; Legislative appropriation / --	$150,000/year in 2005 and 2006

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
DORA13 - Gizzard shad harvest	Lake Dora in-lake removal of fish / Harvest of gizzard shad by commercial fishermen. Part of experimental assessment with UF and FWC. Removal of fish removes nutrient from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2831B	SJRWMD / SJRMWD Ad valorem; Legislative appropriation / --	$150,000/year in 2005 and 2006
EUS25 - Pine Meadows Restoration Area	Pine Meadows Restoration Area. Muck farm is east of Trout Lake and discharges to Hicks Ditch. / Reduce TP loadings from former muck farm. Restore aquatic, wetland, and riverine habitat. Chemical treatment of soil (alum) to bind phosphates. Reduce nutrient outflow to feasible level of 1.1 kg/ha/yr of TP, or about 1 lb. per acre. Trout Lake is tributary to Lake Eustis. Reduction in nutrient loading benefits both Lake Eustis and Trout Lake.	1,487 - Lake Eustis; 726 - Trout Lake	2817B	SJRWMD / SJRWMD / --	$1,300,000 combined cost for both lakes
GRIF01 - Lake Griffin Emeralda Marsh Restoration	Emeralda Marsh Conservation Area (northeast marshes) north of Haines Creek /Lake Griffin Emeralda Marsh restoration: To be managed for wetland restoration, planting; alum treatment to bind phosphates in sediments; manage excess nutrient outflow. Remove phosphates and TSS, wetland habitat restoration. Manage nutrient outflow to Lake Griffin to feasible loading of 1.1 kg/ha/yr, or about 1 lb. per acre.	41,450	2814A	SJRWMD / SJRWMD Ad valorem; Legislative appropriation / --	$15,000,000 for land acquisition

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
GRIF02 - Gizzard Shad Harvest	Lake Griffin in-lake removal of fish / Gizzard shad removal from Lake Griffin by commercial fishermen. Expanded to Lake Dora and Lake Beauclair, with possible future expansion to other lakes in Harris Chain. Remove and export nutrients via fish. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2814A	SJRWMD / SJRWMD Ad valorem; Legislative appropriation; LCWA / --	$1,000,000 spent since 2002 harvest
HAR02 - Lake Harris Conservation Area	North shore of Lake Harris / Restoration of former muck farm. Chemical treatment of soil (alum) to bind phosphates for nutrient control. Aquatic and wetland habitat restoration. Reduce and manage nutrient outflow to Lake Harris to feasible loading of 1.1 kg/ha/yr, or about 1 lb. per acre.	6,665	2838A	SJRWMD / Ad valorem; Legislative appropriation / --	$550,000
HAR03 - Harris Bayou Conveyance Project	Harris Conservation Area to Lake Griffin/ Establish water flow connection to Lake Griffin. Modification of hydrodynamics to accommodate higher flows of water.	Unknown	2838A	SJRWMD / Ad valorem; Legislative appropriation / --	$5,000,000
LAP05 - Lake Apopka Constructed Marsh flow-way Phase 1	Northwest shore of Lake Apopka / Constructed marsh on northwest shore of lake. Lake water pumped through marsh to remove particulates and nutrients from lake water. Marsh designed to treat about 150 cubic feet per second (cfs).	External reduction: 4,864 and flow-way: 17,640 to 22,050	2835D	SJRWMD / SJRWMD – SWIM Legislative Appropriation/ Ad Valorem/Beltway Mitigation Lake County/LCWA - $1,000,000 EPA - $1,000,000 / LCWA/ Lake County/EPA	Total $~15 million in land acquisition / $4.32 million Phase 1 flow-way construction
LAP06 - North Shore Restoration	North shore of Lake Apopka / Wetland habitat restoration. Remediate pesticide "hot spots" in soil.	99,960	2835D	SJRWMD / SJRWMD/Legislative appropriation - P2000:SOR: CARL; USDA WRP / USDA	$~100 million in land acquisition

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
LAP07 - With-in Lake Habitat Restoration Area	Lake Apopka / Planting of wetland vegetation in littoral zone, largely north shore. Helps improve fishery, improves water quality and may reduce nutrient levels, stabilize bottom, and reduce TSS.	Unknown	2835D	SJRWMD / SJRWMD ad valorem / --	~$10,000 annually
LAP08 - Removal of Gizzard Shad	Lake Apopka / Harvest of gizzard shad by commercial fishermen. Removal of fish removes nutrient from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2835D	SJRWMD / SJRWMD ad valorem; Lake County; LCWA; Legislature appropriation / Lake County/LCWA	~$500,000 annually
TROUT01 - Pine Meadows Restoration Area	Pine Meadows Restoration Area. Muck farm is east of Trout Lake and discharges to Hicks Ditch. / Reduce TP loadings from former muck farm. Restore aquatic, wetland, and riverine habitat. Chemical treatment of soil (alum) to bind phosphates. Reduce nutrient outflow to feasible level of 1.1 kg/ha/yr of TP, or about 1 lb. per acre. Trout Lake is a tributary to Lake Eustis. Reduction in nutrient loading benefits both Lake Eustis and Trout Lake.	1,487 - Lake Eustis; 726 - Trout Lake	2817B; 2819A	SJRWMD / SJRWMD / --	$1,300,000 combined cost for both lakes

Source: UOBWG (2007)

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APPENDIX B: COST-BENEFIT ANALYSES OF NUTRIENT RULEMAKINGS

The literature review summarized in Section III does not include studies with estimates of the benefits of reduced nutrient loadings, nor does it include the anticipated impacts associated with particular rulemaking proposals. Table B-1 summarizes some benefit-cost studies of planned nutrient pollution rulemaking at the state level.

Table B-1. Summary of State Level Cost-Benefit and Economic Analyses of Proposed Nutrient Reduction Regulations

Study	Location	Description of Rulemaking	Description of Study
CDPHE (2011)	CO	Establishment of technology-based controls on facilities that discharge nutrients to Colorado waters, specifically domestic and nondomestic wastewater treatment facilities.	Assessment of the expected costs, environmental benefits, and drinking water treatment cost reductions. Benefits that were assessed only qualitatively include potable water supplies (substantial), property values (potentially substantial), recreational activities (moderate), intrinsic values (unknown), and agriculture (minimal).
UDWQ (2013)	UT	Potential nutrient removal requirements for publicly owned treatment works statewide.	Contingent valuation survey to estimate statewide willingness-to-pay to either maintain current water quality or to improve water quality (improving means reclassifying 78% of "poor" waterbodies to "fair," and 20% of "fair" to "good." Costs are quantified, in a separate report—UDWQ (2010)—by analyzing four potential discharge levels or tiers for model publicly owned treatment works.
U.S. EPA (2010)	FL	Numeric nutrient criteria for Florida lakes and flowing waters.	Potential costs for point and nonpoint source controls that may be needed to attain the criteria. Benefits include transfer of water treatment plant function for incremental water quality improvements at the waterbody level expected to result from compliance with proposed numeric nutrient criteria, aggregated across all waters expected to improve as a result of numeric nutrient criteria.
U.S. EPA (2012)	FL	Numeric nutrient criteria for Florida estuaries, coastal waters, and South Florida inland flowing waters.	Potential costs for point and nonpoint source controls that may be needed to attain the criteria. Benefits include transfer of water treatment plant function for incremental water quality improvements at the waterbody level expected to result from compliance with proposed numeric nutrient criteria, aggregated across all waters expected to improve as a result of numeric nutrient criteria.
WDNR (2012)	WI	Regulations to decrease phosphorus discharges from industrial and municipal dischargers, adopted June 2010.	Benefits transfer for property values (based on Dodds et al. 2009) and recreational benefits (from Kaval and Loomis 2003); avoided cost methods to estimate reductions in need for managing algal blooms.

References cited in Appendix B.

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APPENDIX C: ANECDOTAL POINT SOURCE CONTROL COSTS

Table C-1 shows costs for biological nutrient removal (BNR) and enhanced nutrient removal (ENR) at wastewater treatment plants (WWTPs) in Maryland (MDE 2012). Listed costs are for state grant funds for BNR and ENR upgrades, total upgrade funds originating from all other sources, and the total upgrade cost for BNR and ENR (i.e., the sum of state funding and other funding). For projects that have a listed completion date for both BNR and ENR, the reported costs are actual; for all others, reported costs are a combination of actual BNR costs and projected ENR costs.

Table C-1. Costs for BNR and ENR at WWTPs in Maryland

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expansion	After Expansion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
ABERDEEN	4	--	1998	--	$1,317,417	$14,982,000	$13,079,817	$29,379,234
ANNAPOLIS	13	--	2000	--	$2,994,313	$13,700,000	$23,495,778	$40,190,091
APG-ABERDEEN*	2.8	--	2006	2006	$0	$0	Unknown	Unknown
BACK RIVER (BNR REFINEMENT)	180	--	1998	--	$73,135,745	$267,000,000	$218,592,442	$558,728,187
BALLENGER CREEK	6	15	1995	--	$1,000,000	$31,000,000	$111,033,621	$143,033,621
BLUE PLAINS (Grants MD PORTION)	169.6	--	--	--	$38,831,231	$203,298,000	$837,870,769	$1,080,000,000
BOONSBORO (MINOR; STATE $ FOR BNR ONLY)	0.53	--	2010	2010	$2,601,676	$0	$9,954,718	$12,556,394
BOWIE	3.3	--	1991	2011	$96,960	$8,870,000	$1,986,799	$10,953,759
BROADNECK	6	8	1994	--	$206,897	$7,851,000	$21,161,593	$29,219,490
BROADWATER	2	--	2000	--	$2,589,960	$6,000,000	$9,694,382	$18,284,342
BRUNSWICK	1.4	--	2008	2008	$2,333,661	$8,263,000	$4,029,488	$14,626,149
CAMBRIDGE	8.1	--	2003		$4,728,221	$8,944,000	$11,039,167	$24,711,388
CELANESE	1.66	--	2006	2006	$3,606,579	$2,333,382	$10,154,290	$16,094,251
CENTREVILLE***	0.5	--	2005	--	$3,279,858	$1,000,000	$6,382,042	$10,661,900
CHESAPEAKE BEACH	1.18	--	1992	--	$0	$9,157,000	$20,688,400	$29,845,400
CHESTERTOWN	0.9	--	2008	2008	$2,858,405	$1,490,854	$5,452,355	$9,801,614
CONOCOCHEAGUE	4.1	4.5	2001	--	$2,612,390	$27,537,000	$12,606,897	$42,756,287
COX CREEK	15	--	2002	--	$4,265,000	$140,485,000	$27,371,580	$172,121,580
CRISFIELD	1	--	2010	2010	$1,986,639	$4,231,000	$4,052,884	$10,270,523
CUMBERLAND	15	--	2001	2011	$5,091,863	$26,780,000	$15,264,198	$47,136,060
DAMASCUS	1.5	--	1998	--	$830,600	$5,235,000	$26,186,280	$32,251,880
DELMAR	0.65	--	--	--	$515,000	$2,540,000	$4,755,793	$7,810,793

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expan sion	After Expan sion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
DENTON	0.8	--	2000	--	$1,879,935	$4,609,000	$4,748,326	$11,237,261
DORSEY RUN***	2	--	1992	--	$0	$3,900,000	$0	$3,900,000
EASTON	2.35	--	2007	2007	$8,930,000	$8,660,000	$21,563,791	$39,153,791
ELKTON	2.7	3.2	2009	2009	$8,842,410	$7,960,000	$23,908,502	$40,710,912
EMMITSBURG	0.75	--			$5,346,000	$8,153,000	$10,361,000	$23,860,000
FEDERALSBURG	0.75	--	2010	2010	$2,360,000	$3,360,000	$3,767,713	$9,487,713
FREDERICK (BNR REFINEMENT)	8	10.49	2002	--	$8,450,281	$27,411,000	$37,739,915	$73,601,196
FREEDOM DISTRICT (BNR REFINEMENT)	3.5	--	1994	--	$4,834,000	$7,891,000	$20,444,118	$33,169,118
FRUITLAND	0.8	1.06	2003	--	$3,192,975	$3,100,000	$9,009,000	$15,301,975
GEORGES CREEK	0.6	--	2010	2010	$5,984,613	$10,588,000	$12,092,306	$28,664,919
HAGERSTOWN	8	10.5	2000	2010	$4,359,643	$10,860,000	$11,851,425	$27,071,068
HAMPSTEAD	0.9	--	--	--	$10,000,000	$2,000,000	$10,000,000	$22,000,000
HAVRE DE GRACE (BNR REFINEMENT)	1.89	3.3	2002	--	$8,722,976	$11,289,000	$33,885,998	$53,897,974
HURLOCK	1.65	--	2006	2006	$2,507,171	$941,148	$4,137,043	$7,585,362
INDIAN HEAD	0.5	--	2008	2008	$2,560,860	$6,484,000	$5,896,777	$14,941,637
JOPPATOWNE	0.95	--	1996	--	$464,299	$2,999,732	$4,317,815	$7,781,846
KENT ISLAND	3	--	2007	2007	$7,838,606	$6,380,645	$19,773,557	$33,992,808
LA PLATA	1.5	--	2003	--	$2,046,387	$9,378,000	$9,081,613	$20,506,000
LEONARDTOWN	0.68	1.2	2003	--	$1,189,501	$6,951,000	$13,003,146	$21,143,647
LITTLE PATUXENT	25	29	1994	--	$2,000,000	$35,494,000	$94,218,500	$131,712,500
MARLAY TAYLOR (PINE HILL RUN)	6	--	1998	--	$1,865,859	$11,000,000	$28,059,978	$40,925,837
MARYLAND CITY	2.5	--	1990	--	$0	$3,400,000	$5,000,000	$8,400,000
MARYLAND CORRECTIONAL INSTITUTE***	1.6	--	1995	--	$0	$3,000,000	$0	$3,000,000
MATTAWOMAN***	15	--	2007	--	$10,000,000	$0	$19,491,191	$29,491,191
MAYO LARGE COMMUNAL	0.615	1.14	--	--	$5,456,000	$3,000,000	$31,304,000	$39,760,000
MOUNT AIRY	1.2	--	1999	2010	$2,005,000	$3,500,000	$3,638,869	$9,143,869
NORTHEAST RIVER	2	--	2005	--	$1,675,927	$9,000,000	$24,709,795	$35,385,722
PARKWAY	7.5	--	1992	--	$5,000,000	$16,052,000	$12,998,114	$34,050,114
PATAPSCO	73	81	--	--	$75,150,000	$218,500,000	$97,546,400	$391,196,400
PATUXENT	7.5	--	1999	--	$500,000	$13,800,000	$7,384,690	$21,684,690
PERRYVILLE	1.65	--	2010	2010	$3,243,974	$4,000,000	$6,516,104	$13,760,078

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expansion	After Expansion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
PISCATAWAY	30	--	2000	--	$9,642,175	$6,324,000	$11,035,767	$27,001,942
POCOMOKE CITY	1.47	--	2004	--	$1,578,539	$3,224,000	$3,426,249	$8,228,788
POOLESVILLE	0.75	--	1995	2010	$692,381	$235,000	$2,320,519	$3,247,900
PRINCESS ANNE	1.26	--	2004		$1,701,116	$4,000,000	$2,479,064	$8,180,180
SALISBURY	8.5	--	2010	2010	$22,817,000	$3,000,000	$52,203,887	$78,020,887
SALISBURY CORRECTIVE ACTION	--	--	--	--	$11,000,000	$12,000,000	$31,270,000	$54,270,000
SENECA	20	26	2003	--	$12,011,129	$6,900,000	$93,188,812	$112,099,941
SNOW HILL	0.5	0.667		--	$3,765,000	$3,527,000	$7,072,870	$14,364,870
SOD RUN	20	--	2000	--	$8,249,178	$42,633,450	$46,843,650	$97,726,278
SWAN POINT**	0.6	--	2007	2007	$0	$0	Unknown	Unknown
TALBOT COUNTY REGION II (St. Michael's)	0.66	--	2008	2008	$2,729,349	$2,000,000	$8,306,928	$13,036,277
TANEYTOWN	1.1	--	2000	--	$1,497,408	$2,870,000	$6,886,587	$11,253,995
THURMONT	1	--	1996	--	$926,660	$6,889,000	$5,426,115	$13,241,775
WESTERN BRANCH	30	--	1995	--	$15,739,370	$29,000,000	$66,394,690	$111,134,060
WESTMINSTER	5	--	2001	--	$2,036,263	$16,940,000	$13,239,584	$32,215,847
WINEBRENNER	1	--	--	--	$2,100,000	$7,000,000	$8,565,200	$17,665,200

Source: Maryland Department of the Environment (MDE). 2012. Cost Estimates for Phase II WIP.
BNR = biological nutrient removal
ENR = enhanced nutrient removal
mgd = million gallons per day
** Funded by the U.S. Army.*
*** Funded by private developer*
**** Based on current performance, ENR upgrade may not be required. Further evaluation is necessary.*

Appendix D: References for Benefit Studies

The literature review summarized in Section III does not include studies with estimates of the benefits of reduced nutrient loadings, nor does it include the anticipated impacts associated with particular rulemaking proposals. Table B-1 lists several such studies that evaluate benefits. In addition, Table B-2 summarizes some benefit-cost studies of planned nutrient pollution rulemaking at the state level.

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Appendix E: Municipal WWTP Technology Abbreviations and Acronyms

3Clar	tertiary clarification
A2O	three-stage phoredox
AB	aeration basin
AL	aerobic lagoons
AO	phoredox
AS	activated sludge
BAF	biological activated filter
BNR	unspecified biological nutrient removal process
Bpho	bardenpho
BPR	unspecified biological phosphorus removal process
CA	cycled aeration
CAC	chemically assisted clarification
ChPr	chemical phosphorus removal
DFil	denitrification filter
EA	extended aeration
Ferm	fermenter
Fil	media filtration (does not include granular activated carbon)
FL	facultative lagoon
GAAl	granular activated aluminum
GR	grit removal
IFAS	integrated fixed-film activated sludge
MemBR	membrane bioreactor
MiFil	microfiltration
MLE	modified Ludzack-Ettinger
POD	phased oxidation or isolation ditch
OX	oxidation ditch
RBC	rotating biological contactor
RO	reverse osmosis
SBR	sequential batch reactor

SF	sand filter
SubF	submerged biological filter
TF	trickling filter
UCT	university of capetown process
UF	ultrafiltration

Note: Sequenced processes should be denoted by "___ + ___". (i.e., Activated sludge followed by filtration would be "AS + Fil").

Appendix F: Users' Guide for the EPA's Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution

A. Introduction

This appendix provides instructions for the navigation and use of a database containing references, data tables and diagrams that the EPA assembled for its compilation of cost data associated with the impacts and control of nutrient pollution. The data and information contained in the database serve as the basis for this report. The database provides baseline information for developing and/or evaluating cost estimates, which might be useful in various contexts, including policy-making and nutrient criteria adoption. Information on both the impacts and control of nutrient pollution will allow users to gather information on the costs of nutrient controls as well as the impacts of uncontrolled nutrient pollution in an effort to develop a range of management approaches.

The database provides information on the costs associated with point source controls, nonpoint source controls, direct mitigation of nutrient pollution in waterbodies, and restoration efforts. It also includes diagrams showing the pathways for impacts of nutrients on lakes, streams, estuaries, and coasts, and a summary of the literature on economic impacts and control costs. Relevant studies are described in tabs organized according to economic sector (including commercial fisheries, tourism/recreation, property values, health effects, and drinking water treatment) and type of control activity. Sources that are relevant to economic impacts of nutrient pollution but do not meet all the evaluation criteria are included as anecdotal impacts or additional studies (as described below). Finally, cost-benefit and economic analyses supporting state-level nutrient rulemakings are briefly summarized.

The EPA is sharing the database so that users can find the source material from the report. A user who is interested in learning more about a particular study or is interested in gathering information from a specific geographic location can use this database to find those data. We have provided two examples of how to use this database at the end of this User's Guide.

B. Database Navigation and Use

The database was developed using Microsoft Excel™. Use of the database assumes users have a working knowledge of Microsoft Excel™ functions. The database is organized as a series of worksheets that are listed at the bottom of the database page. The "**Instructions**" worksheet provides some general instructions on how to use the database to access the data and information about the economic impacts (i.e., costs) of nutrient pollution and the costs of nutrient pollution control.

1. Navigating Within the Database

The database provides several ways to access the data within. The opening page ("**File Info**" worksheet) of the database acts as the table of contents for the database, where a description of the database and its contents are provided. This worksheet also briefly describes the primary worksheets in the database and provides links to the other worksheets contained in the workbook. While in the "**File Info**" worksheet, the user can click on the name of a worksheet to go directly to that worksheet or scroll through the list of worksheets along the bottom. The user can navigate the list of worksheets using the left-right arrow on the bottom right corner (Figure F-1).

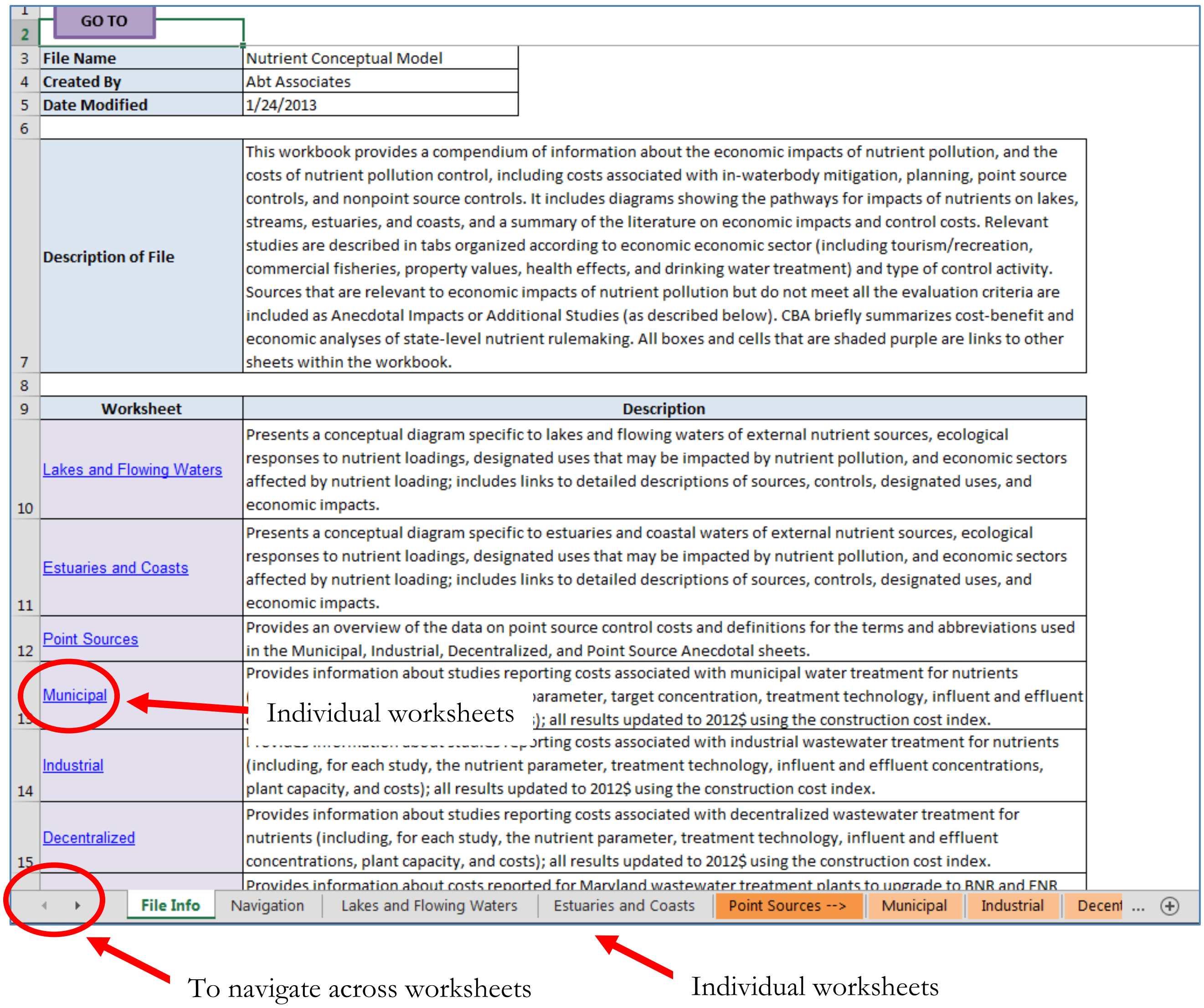

Figure F-1. Opening page of the database – "**File Info**" worksheet. [Note: Worksheets can be accessed from either the titles in the worksheet table or from the list along the bottom. Navigate the list of worksheets using the left-right arrows on the bottom left.]

The second worksheet in the database titled "**Navigation**" also acts as a table of contents for the database by providing a diagram of the organization of the database (Figure F-2). The listing of worksheets generally follows this organization. All of the text boxes in the navigation diagram that are shaded purple are hyperlinks to the relevant worksheet in the database. The user can click on the name of a worksheet in the diagram to go directly to that worksheet in the database or scroll through the list of worksheets along the bottom.

Further, throughout all of the worksheets in the database, purple cells and purple text boxes are hyperlinks to other parts of the database. Along the top left part of each worksheet, there are purple text boxes that provide quick links to other related worksheets. Each text box labeled "GO TO" links back to the Navigation page, where the user can quickly access any other worksheet.

2. Navigating Within Worksheets

Two helpful tools exist to aid users in extracting data from the database: filter tools and Excel's search functionality.

Filtering can be accomplished by clicking on the grey boxes in the lower right-hand corner of each column heading (as indicated in Figure F-3). Once clicked, a drop-down menu will appear which will allow you to filter out elements within the column or to sort the elements within the column. By utilizing the filtering and sorting tools, the user may organize the data within a given page according to options like pollutant type, cost, and geographic location. For example, if the user wished to only look at municipal point source data relating to total nitrogen, the filter function could be used to hide all data specific to total ammonia and total inorganic nitrogen, leaving only data relating to total nitrogen displayed in the worksheet.

In some cases the user may wish to search the database for a value or text string. A search can be accomplished using Excel's "Find" function which can be accessed from the "Editing" menu (see Figure F-4). It can also be accessed using the hotkey sequence "Ctrl"+F—just press the "Ctrl" key and the "F" key on the keyboard simultaneously.

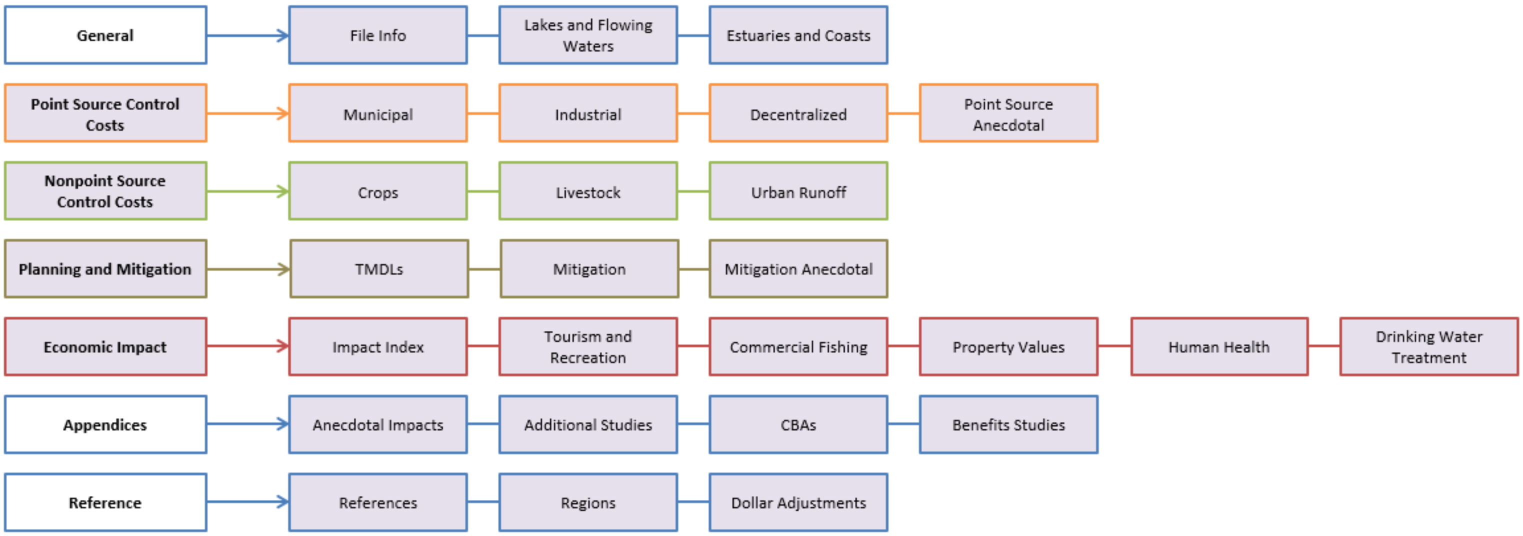

Figure F-2. Organization of the database – "**Navigate**" worksheet. [Note: Worksheets can be accessed from either the boxes in the diagram in the worksheet or from the list along the bottom. Navigate the list of worksheets using the left-right arrows on the bottom left.]

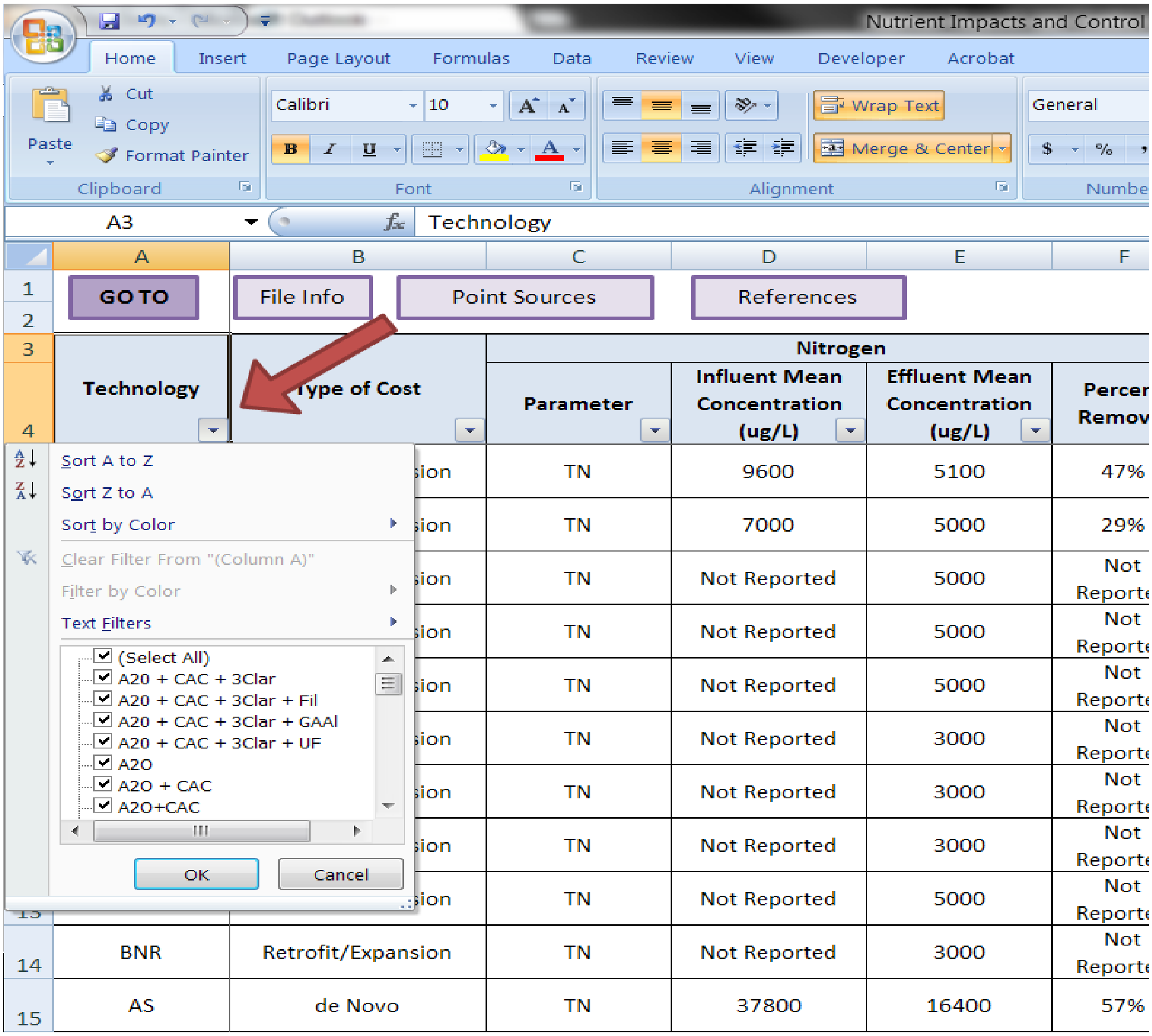

Figure F-3. Filter data using the drop-down menus located in each column heading.

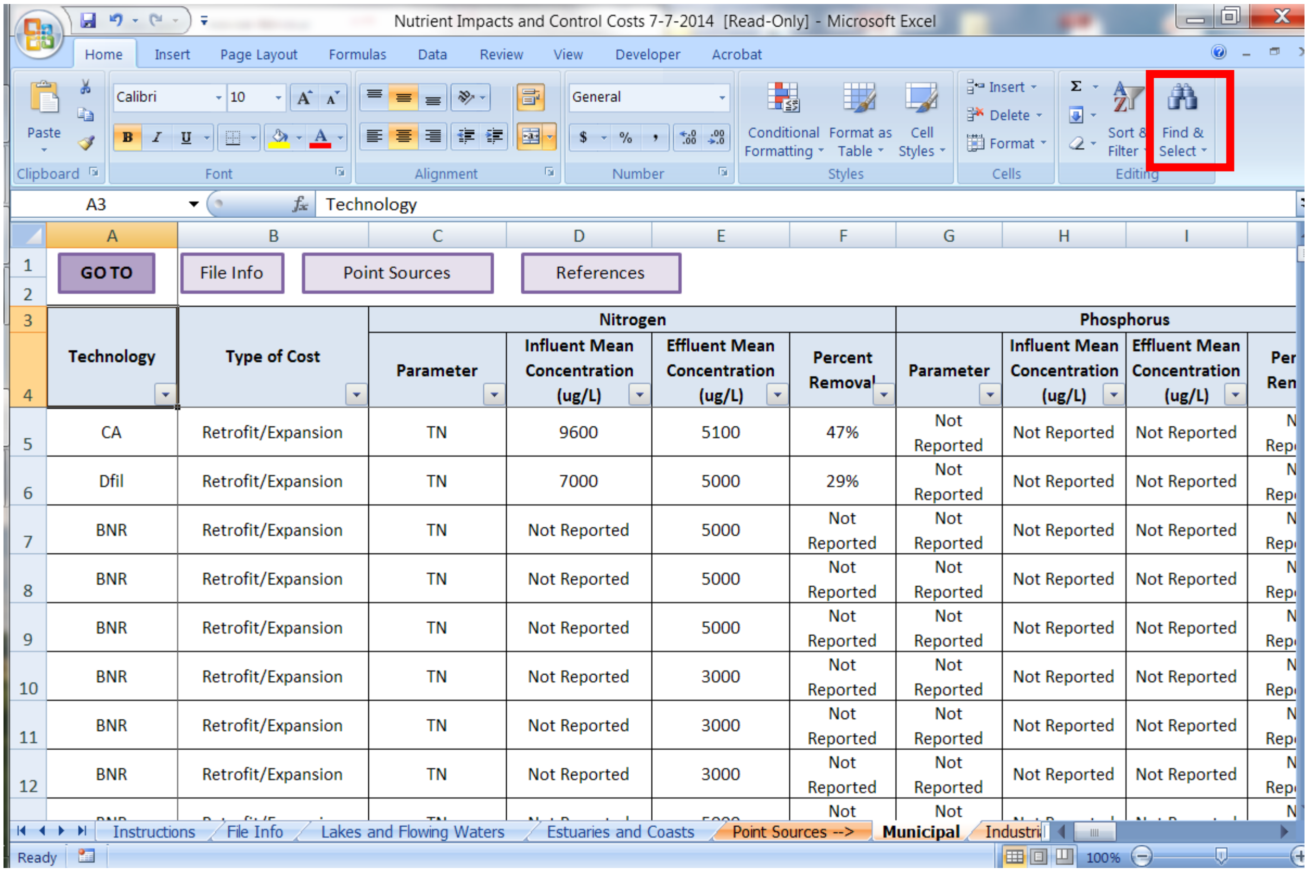

Figure F-4. Search within the worksheets for specific numbers or strings using the "Find" function located in the "Editing" menu.

C. Worksheet Descriptions

This section provides descriptions of each of the worksheets contained in the database. The worksheet descriptions are provided in the same order as they are contained in the database.

1. The worksheet entitled "**Lakes and Flowing Waters**" presents a conceptual diagram specific to lakes and flowing waters of external nutrient sources, ecological responses to nutrient loadings, uses that may be impacted by nutrient pollution, and economic sectors affected by nutrient loading. The worksheet includes links to detailed descriptions of sources, controls, uses, and economic impacts. Similarly, the next worksheet entitled "**Estuaries and Coasts**" presents a conceptual diagram specific to estuaries and coastal waters of external nutrient sources, ecological responses to nutrient loadings, uses that may be impacted by nutrient pollution, and economic sectors affected by nutrient loading. The worksheet includes links to detailed descriptions of sources, controls, uses, and economic impacts.

2. The worksheet entitled "**Point Sources**" provides an overview of the data on point source control costs and definitions for the terms and abbreviations used in the "**Municipal**",

"**Industrial**", "**Decentralized**", and "**Point Source Anecdotal**" worksheets that follow. All results in these worksheets are presented in 2012$ (updated using the construction cost index, unless otherwise indicated).

- "**Municipal**" - provides data and information from studies reporting costs associated with municipal wastewater treatment for nutrients (including, for each study, the nutrient parameter, target concentration, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Industrial**" - provides data and information from studies reporting costs associated with industrial wastewater treatment for nutrients (including, for each study, the nutrient parameter, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Decentralized**" - provides data and information from studies reporting costs associated with decentralized wastewater treatment for nutrients (including, for each study, the nutrient parameter, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Point Source Anecdotal**"- provides information about costs reported for Maryland wastewater treatment plants to upgrade to biological nutrient removal (BNR) and enhanced nutrient removal (ENR) treatment processes (including, for each plant, NPDES permit number, Maryland County, current and expansion treatment capacity, completion year, costs for state grant funds for BNR and ENR upgrades, total upgrade funds originating from all other sources, and the total upgrade cost for BNR and ENR).

3. The next portion of the database covers "**Nonpoint Sources**". The "**Nonpoint Sources**" worksheet provides an overview of the data on nonpoint source control costs and definitions for the terms and abbreviations used in the "**Urban Runoff**" worksheet that follow. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

   - "**Urban Runoff**" - provides data and information from studies reporting costs associated with reducing nutrient pollution from urban runoff (including, for each study, the nutrient parameter, treatment technology, removal performance, size, location, and costs).

4. The "**Restoration and Mitigation**" worksheet provides an overview of the data on restoration and direct mitigation costs and provides definitions for the terms and abbreviations used in "**Restoration**", "**Mitigation**", and "**Mitigation Anecdotal**" worksheets. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

- "**Restoration**" - provides data and information from studies quantifying the costs associated with nutrient reduction (including, for each study, the waterbody type, restoration activity and description, location, year, resource description, water quality impact, data sources, and costs).

- "**Mitigation**" - provides data and information from studies quantifying the costs associated with in-lake nutrient mitigation technologies and methods (including, for each study, the waterbody type, the activity and description, location, year, resource description, water quality impact, data sources, and costs).

- "**Mitigation Anecdotal**" - provides information about water quality improvement projects planned to meet phosphorus load reductions for Florida's Upper Ocklawaha River Basin TMDL (including, for each project, the estimated load reduction, project cost, and completion date). Presented in original dollar years.

5. The worksheet for "**Economic Impacts**" provides an overview of the data on economic impacts presented in the "**Tourism**", "**Fisheries**", "**Property Value**", "**Health Effects**", and "**Drinking Water Treatment**" worksheets. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

- "**Impact Index**" - provides a summary of all documented nutrient impacts in the model. The impacts can be filtered by state, region, year, source categorization, economic sector, or waterbody type.

- "**Tourism**" - provides information about studies valuing nutrient impacts to tourism and recreation (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

- "**Fisheries**" - provides information about studies valuing nutrient impacts to fisheries (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

- "**Property Values**" - provides information about studies valuing nutrient impacts to property values (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

- "**Health Effects**" - provides information about studies valuing nutrient impacts to human health (including, for each study, the waterbody type, location, year, the health effect/measure being evaluated, water quality impacts, data, methodology, and results).

- "**Drinking Water Treatment**" - provides information about studies valuing nutrient impacts to drinking water treatment costs (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

6. The remaining worksheets provide information about studies that did not meet all screening criteria, but have relevant information and results documenting impacts from nutrient pollution.

- "**Anecdotal Impacts**" - provides information about anecdotal evidence of the economic impacts of nutrient pollution.

- "**CBAs**" - Cost Benefit Analysis provides a summary of cost-benefit and economic analyses of state-level nutrient rulemaking.

- "**Benefit Studies**" - provides a list of studies that assess the benefits of nutrient reductions.

- "**References**" - provides full references for all sources used in conceptual diagram.

- "**Regions**" - provides a reference for the region categorizations in the Impact Index.

- "**Dollar Adjustments**" - provides the Consumer Price Index factors used to normalize cost and impact estimates to 2012$ and the construction cost index factors used to normalize drinking water and wastewater treatment cost estimates to 2012$.

D. Examples for Navigating the Database to Extract Data and Information

The following examples illustrate how a user can use the database to gather control cost information.

1. Using Point Source Control Cost Data

- Situation: State is assessing the potential costs that would be incurred by point sources to achieve effluent limitations based on numeric water quality criteria for nitrogen

- Assume: Only one major municipal wastewater treatment facility to be affected; 4 million gallon per day (mgd) WWTP (service population of approximately 40,000 persons) that must meet **5 mg/L TN end-of-pipe limits**

- Approach: Use the project database to assess possible project costs

  Step 1: Navigate to "**Municipal**" point source control costs worksheet

  Step 2: Filter data

- By nitrogen parameter (i.e., "TN")
- By effluent concentration (i.e., show all data ≤5 mg/L)
- By flow (i.e., all systems between 1 mgd and 10 mgd)

Step 3: Assess resulting data

- Potential technologies include: oxidation ditches, trickling filters, denitrification filters, and activated sludge systems designed for biological nutrient removal
- Estimated unit capital costs range from $1/gpd - $5/gpd
- There are fewer data points for annual O&M costs but these range from $0.024/gpd – $0.11/gpd annually

Step 4: Estimate project costs

- Total capital costs are between $4 million - $20 million
- On an annualized basis (assuming a useful life of 20 years and a 3% interest rate) these capital costs are $0.3 million/year – $1.3 million/year
- Assuming annual O&M costs of $0.06/gpd, total annual project costs are anticipated to be between $0.4 million/year – $1.8 million/year
- If desired, user-fee increases could be estimated
  - In this example, fee increases could range between $9/year – $45/year

Step 5 (Optional): Review of anecdotal data to support estimates

- Navigate to "**Point Source Anecdotal**" worksheet
- Filter data by Current Capacity for desired flows; results for those around 4 mgd are shown in Table E-1.

Table F-1. Upgrade Costs for Wastewater Treatment Plants around 4 mgd (million gallons per day) based on Point Source Anecdotal Data.

Plant Name	Current Capacity (MGD)	Expansion Capacity (MGD)	COST SUMMARY				
			Total Upgrade Cost	Total BNR State Share	Total BNR	Total ENR State Share	Total Other
HAVRE DE GRACE (BNR REFINEMENT)	1.89	3.3	$53,897,974	$8,722,976	$17,445,953	$11,289,000	$33,885,998
ELKTON	2.7	3.2	$40,710,912	$8,842,410	$17,684,820	$7,960,000	$23,908,502
KENT ISLAND	3		$33,992,808	$7,838,606	$15,677,212	$6,380,645	$19,773,557
BOWIE	3.3		$10,953,759	$96,960	$193,920	$8,870,000	$1,986,799
FREEDOM DISTRICT (BNR REFINEMENT)	3.5		$33,169,118	$4,834,000	$9,668,000	$7,891,000	$20,444,118
ABERDEEN	4		$29,379,234	$1,317,417	$2,634,834	$14,982,000	$13,079,817
CONOCOCHEAGUE	4.1	4.5	$42,756,287	$2,612,390	$5,224,780	$27,537,000	$12,606,897
WESTMINSTER	5		$32,215,847	$2,036,263	$4,072,526	$16,940,000	$13,239,584

2. Using Nonpoint Source Control Cost Data

- Situation:
  - State desires to assess the potential costs that would be incurred by nonpoint sources to achieve effluent limitations based on numeric water quality criteria for phosphorus
- Assume:
  - A municipal separate storm sewer system (MS4) permit would require **5% TP reduction** in runoff from 200 acre industrial park
  - Existing TP load is 1.5 lbs/acre/year, or 300 lbs/year
  - A 5% reduction is 15 lbs/year

- Approach: Use the project database to assess possible project costs

  Step 1: Navigate to "**Urban Runoff**" nonpoint source control costs worksheet

  Step 2: Filter data
  - By parameter (i.e., "TP")
  - By appropriate technology options (e.g., dry detention basin or "DB")

  Step 3: Assess resulting data
  - A number of data points exist; the State elects to use the most up-to-date empirical cost information (released in 2013) rather than older data based on modeled estimates

  Step 4: Estimate project costs
  - Data from two projects indicate observed total project costs of $21,100/lb TP removed and $10,500/lb TP removed over 20 years

- Based on this unit cost and a desired reduction of 15 lbs TP per year, total project cost could range from approximately $160,000 - $320,000
- Annualized over a 20 year project life and assuming a 3% interest rate, the total project cost is between $10,800/year - $21,500/year
- If desired, cost to users could be estimated
  - Assuming all 40,000 residential users are affected, this translates into an estimated user-fee increase of between $3/year - $11/year.