# Phosphorus Control at Municipal Wastewater Treatment Plants

A thesis

submitted by

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In partial fulfillment of the requirements

for the degree of

Master of Arts

in

Urban and Environmental Policy and Planning

TUFTS UNIVERSITY

August, 2012

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READER: Scott Horsley

## Abstract

This thesis addresses phosphorus management at three wastewater treatment plants in an effort to better understand the challenges, and potential solutions, in meeting stricter state and federal regulations regarding phosphorus levels in processed wastewater. The three treatment plants are located in three different states, all facing different issues involving population growth, budgetary constraints, and phosphorus regulation. The research into these sites reveals how the different approaches to phosphorus regulation have affected the treatment plants over time, as well as how new regulations and changing cities are impacting future planning through reduced budgets and/or increased demand. Finally, the thesis concludes that while the three sites have dealt with different issues around the management of phosphorus in their treated wastewater, the common approaches to successfully addressing these challenges were close coordination with the city when it came to capacity and budgetary concerns, as well active participation in the regulatory permitting process.

## Acknowledgements

I am truly grateful for the people who have helped and supported me during my time in graduate school. First and foremost, I would like to thank my advisor, Shelly Krimsky, for his support, guidance, and encouragement during both the thesis process and throughout my graduate career. I would also like to thank my reader, Scott Horsley, for his insight, suggestions, and for helping me discover my interest in water management.

Thank you to the interview participants who took the time to share their experience, insights, and advice: Alan Cathcart and Hardik Raval, Concord Public Works; David Pincumbe, U.S. Environmental Protection Agency, Region 1; Eric Pierce, Parker Water and Sanitation District; Andrew Neuhart, Colorado Department of Public Health and Environment; Michael Forbes, Bemidji Wastewater Treatment Facility; and Steven Heiskary, Minnesota Pollution Control Agency.

A thank you is owed to many friends, family, and colleagues that have provided support throughout the thesis process and graduate school. In particular, the time, guidance, and advice of Dr. Jason Margolis has been invaluable in starting, writing, and finally completing this thesis. I owe a special thanks to my parents, Rosemary and Charles Colson, for their support and encouragement of lifelong learning. Also, thank you to Maria Margolis, Judy Moore, and Dale Moore for their advice and motivational support.

Finally, I am forever indebted to my husband, Paul Moore, for his help during many late night proofreading sessions, and for providing endless encouragement, support, and patience throughout my time in graduate school.

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## Acronyms and Abbreviations

| | |
|---|---|
| BOD | Biochemical oxygen demand |
| CO DPHE | Colorado Department of Public Health and the Environment |
| CWA | Clean Water Act |
| CWSRF | Clean Water State Revolving Fund |
| FWPCA | Federal Water Pollution Control Act |
| FY | Fiscal year |
| HAB | Harmful algal bloom |
| MassDEP | Massachusetts Department of Environmental Protection |
| MGD | Million gallons per day |
| mg/L | Milligrams per liter |
| MNPCA | Minnesota Pollution Control Agency |
| NPDES | National Pollutant Discharge Elimination System |
| POTW | Publicly Owned Treatment Works |
| PWSD | Parker Water and Sanitation District |
| TMDL | Total maximum daily load |
| TP | Total phosphorus |
| TSS | Total suspended solids |
| USEPA | United States Environmental Protection Agency |
| WWTP | Wastewater treatment plant |

# Chapter 1

## Introduction and Background

In the United States, phosphorus (P) and nitrogen (N), commonly referred to as nutrients, are the second most common cause of water impairment in freshwater lakes, reservoirs, and ponds, and the third most common cause of impairment in rivers and streams (United States Environmental Protection Agency [USEPA], 2011a). Despite pollution controls in place throughout the country, the contamination of water bodies due to nutrients remains greater than the established water quality standards. Approximately 101,800 miles of water in rivers and streams and over 3.5 million acres of lakes, reservoirs, and ponds in the United States are listed with the EPA as impaired due to nutrients (USEPA, 2011a).

Eutrophication, a change in a surface water body causing it to become biologically over productive, can lead to harmful algal blooms, which can negatively impact the water quality through taste, odor, and other undesirable conditions. Elevated levels of phosphorus alone, nitrogen alone, or a combination of the two can cause eutrophication. Although the decision to reduce either phosphorus or nitrogen from a eutrophic water body depends upon the individual characteristics of the water body, when algal blooms from eutrophication develop in a freshwater ecosystem, the nutrient of greatest concern is typically phosphorus (Schindler, 1977; Blomqvist, 2004; Schindler et al., 2008). Due to the abundance of phosphorus in this country’s water bodies and its impact on freshwater quality, and this thesis' focus on freshwater ecosystems, the research efforts presented here target phosphorus alone.

Although the synthesis of phosphorus is not toxic to either humans or animals, the effects of eutrophication do pose risks to human health. Neither organic nor inorganic phosphorus is toxic in small amounts, but it can reach toxic levels if an excess is consumed. Among the public health concerns are risks from direct exposure to drinking water produced from eutrophic areas where algal blooms have resulted in waterborne toxins, and consumption of food contaminated with toxins (Chorus and Bartram, 1999; Pitois, et al., 2010). In addition, potential carcinogens can be created when chemicals used to disinfect wastewater treatment plant (WWTP) effluent react with the increased organic matter present in the eutrophic surface water (Krasner, et al., 2009; IARC, 2010).

The source of phosphorus contamination can be naturally occurring from plants and animals, or it can be related to human activities, such as effluent from septic systems, WWTPs, or stormwater and agricultural run-off. For a growing number of communities, the water bodies that receive effluent from WWTPs are seeing an increasing level of environmental and public health concerns relating to a reduction in water quality. Although the minimum water quality standards are specified by the United States Environmental Protection Agency (USEPA), state governments are responsible for water body impairment determinations and the development of total maximum daily loads of pollutants for the waters. Some state governments have responded to water quality concerns by establishing water quality guidelines more stringent than federal standards set by USEPA. As

WWTP effluent is one of the most common point sources for water contamination and the effluent can contain high concentrations of phosphorus, this thesis will analyze three WWTPs in areas where local governments are attempting to increase water quality by raising standards to a lower phosphorus tolerance level. This will be achieved via a *case study analysis of three municipalities* who are all under pressure to reduce the quantity of phosphorus in their WWTP effluent.

*Background and significance*

In 1972, public sewer systems discharged untreated waste in more than 1,300 communities, and an equal number of communities were only provided primary wastewater treatment, which removes only 30 percent of some pollutants (USEPA, 1972). As seen in Figure 1, only 7.8 million people, approximately four percent of the United State population, were provided with advanced wastewater treatment in 1972. However, as of 2008, 113.0 million people, approximately 37 percent of the United States population, were provided with advanced wastewater

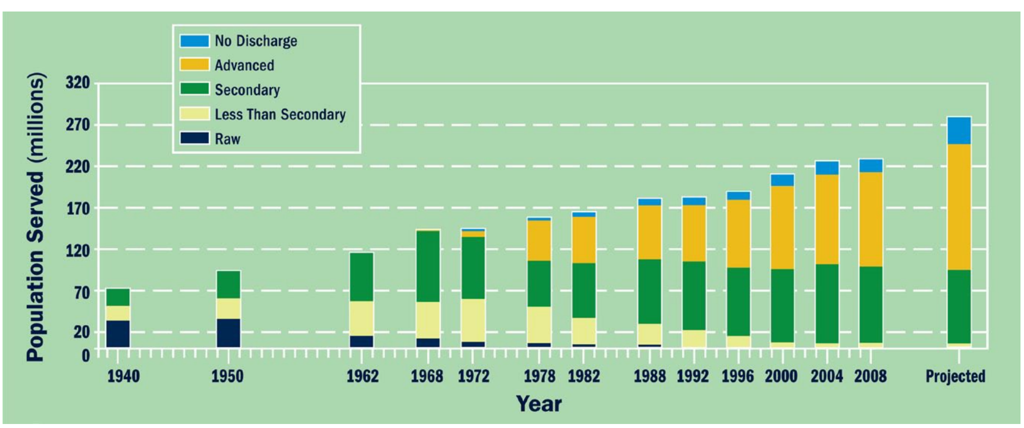


Figure 1. Population served by POTWs nationwide for select years between 1940 and 2004 and projected to 2024 (if all needs are met), by wastewater treatment type. (United States Public Health Service and USEPA, 2010).

treatment, leaving only 3.8 million people with less than secondary wastewater treatment (United States Public Health Service and USEPA, 2010).

Prior to WWTPs, when sewage was disposed of into waterways, the natural process of wastewater purification began with dilution in the pure waters, followed by the consumption of organic matter by bacteria and small organisms in the water. This natural process is not presently used, as it is not feasible to dispose of the increased wastewater volume brought about by population growth. Modern wastewater treatment processes have been developed to deal with the greater volume of wastewater by increasing the rate of water purification. Further, the wastewater treatment processes used by this country's WWTPs are some of the most standardized methods of pollution control in the United States.

Wastewater from both of residential and commercial users is carried to local WWTPs through sewer systems. WWTPs can incorporate primary (mechanical), secondary (biological), and tertiary treatment processes to remove pollutants. Primary treatment involves passing water through varying screens and settling for the removal of large particles. In general, primary treatment has been unable to meet many communities' need for higher water quality. To meet this need, secondary treatment has been added to the treatment process, which introduces bacteria to break down further pollutants and removes a significant amount of organic matter. The remaining bacteria are then typically disinfected with chemicals, and the effluent, or treated water, is piped back to local water bodies. In an increasing number of communities, further protection of the receiving waters is needed by means of tertiary, or advanced, wastewater treatment through additional processes and equipment to remove more organics and solids or nutrients and/or toxic materials.

*Research Questions*

This thesis will address the central question: How can wastewater treatment plants address increased concerns over environmental levels of phosphorus and conform to new regulations that raise wastewater discharge standards to a lower phosphorus tolerance level? In so doing, the following will be explored:

- What are some of the challenges in achieving lower phosphorus levels?
- To what extent are the community study areas interested in public health in contrast to environmental quality as it relates to phosphorus?

In an effort to answer these questions, Chapter Two reviews the existing literature regarding regulation of water quality, the use of phosphorus regulation in addressing public and environmental health, and the challenges faced by municipal WWTPs. Chapter Three provides an explanation and justification of the methodological tools utilized in this research and Chapter Four presents the data collected during the three case studies. A final discussion and cross-case analysis is presented in Chapter Five.

# Chapter 2

## Literature Review

This chapter is intended to provide a more thorough understanding of WWTPs within the context of phosphorus regulation. The review starts with an examination of the development of water quality regulations in the United States and then explores the relationship between phosphorus, eutrophication, and public health. This is followed by a study of the efficacy of total maximum daily loads (TMDLs) and the environmental health benefits of lower phosphorus regulations on WWTPs. Finally, I consider the challenges municipalities face in implementing such regulations, and how they have negotiated those dilemmas.

### *Development of Water Quality Regulations*

Early federal water quality regulations addressed various forms of water pollution, rather than water quality. Following the 1824 United States Supreme Court ruling *Gibbons v. Ogden*, that affirmed Congressional power to control the navigable waters of the United States, Congress began enacting statues supporting navigation and commerce (Downing, et al., 2003). Eventually, the federal government began addressing the control of water pollution through the Rivers and Harbors Act of 1899, which was intended to prevent obstructions to the navigation of waterways. However, although environmental problems of water pollution were left to state governments, the states did not enact or implement effective control or prevention laws (Downing, et al., 2003).

The United States Federal Water Pollution Control Act (FWPCA), enacted in 1948, reorganized and expanded in 1972, and further amended in 1977 and 1987, was in response to the need for a comprehensive effort to control water pollution within the authority of the federal government (Downing, et al., 2003). In the late 1960s, water quality began to receive more attention and a greater level of public awareness, partially due to the 1969 Cuyahoga River fire in Cleveland, Ohio (Migliaccio, et al., 2011). As a result, in 1972, amendments to the FWPCA were passed to help protect and improve water quality. The purpose of the 1972 act, also commonly referred to as the Clean Water Act (CWA), was to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” (Clean Water Act, 1972).

In an effort to protect the nation's public drinking water, the CWA created the basic structure for regulating discharges of pollutants into the waters of the United States and establishing quality standards for surface waters. This legislation specifically focused on point source pollution while establishing a national goal for water pollution policy. One of the major departures from the FWPCA, brought about by the CWA, was the establishment in 1970 of a federal agency, the USEPA, which was given the responsibility of issuing permits to entities discharging into the waters of the United States (Migliaccio, et al., 2011).

Among the programs the CWA established, are the National Pollutant Discharge Elimination System (NPDES) Program and the TMDL Program. The NPDES Program determines the limits for the amount of pollutants discharged from point sources, including municipal and industrial discharges, into receiving waters through a permit system (USEPA, 2011b). The TMDL Program deals with section 303(d) of the CWA, which requires states, territories, and authorized tribes to identify and develop both lists of their impaired waters and any associated TMDLs, a calculation of the maximum amount of a specific pollutant that each impaired water body can receive and still meet water quality standards, that may be needed. (USEPA, 2011c)

*Phosphorus, Eutrophication, and Public Health*

As mentioned previously, phosphorus can be found naturally in aquatic ecosystems due to aquatic organisms, wildlife wastes, or dissolved minerals containing phosphorus. However, it is increasingly coming from anthropogenic sources such as fertilizer, pet waste, and wastewater disposal. Although phosphorus is an essential nutrient required for plant growth, inorganic phosphorus[1] and nitrogen are the nutrients found to limit the growth of algae and vascular plants (Howarth, 1988). While inorganic phosphorus is the most significant form of phosphorus in terms of aquatic plant and algae growth, it is common for water quality-related permits to only specify the total phosphorus (TP) level, which includes both inorganic and organic phosphorus. Between phosphorus and nitrogen, it has been noted that phosphorus is the most growth-limiting element in freshwater because it occurs in the least amount relative to the needs of plants (Lee, 1973; Murphy, 2007). If an excess of phosphorus is added to

[1] In aquatic ecosystems, phosphorus is typically found in the form of inorganic or organic phosphate. Organic phosphate is a phosphate that is associated with plant or animal tissue, or bonded to some other form of carbon compound. Inorganic phosphorus is not associated with organic material, and is the form required by plants for growth.

water, aquatic plants and algae grow in large quantities (Murphy, 2007). Similarly, lakes limited by phosphorus demonstrate a linear relationship between TP and chlorophyll (Horne and Goldman, 1994).

Water bodies with excessive levels of nutrients are said to be eutrophic, or well nourished. While some water bodies are naturally eutrophic, others have lower nutrient concentration and associated plant growth that can be accelerated by anthropogenic activities. The increased nutrient levels and plant growth due to human activity is designated as "cultural eutrophication," although environmental and economic phosphorus-related impacts on water bodies have generally become encompassed within the more general term "eutrophication" (Smith, 2003).

Cultural eutrophication has a number of potential side effects, including decreased water transparency, increased plant growth, shifts to bloom-forming algal species, and an increased frequency and intensity of algal blooms (Smith and Schindler, 2009). Although an abundance of nutrients are not the sole cause of harmful algal blooms (HABs), eutrophication has been shown to directly stimulate some specific HABs (Anderson, et al., 2002; Anderson, et al., 2008). In freshwater, the most common toxin-producing algae is cyanobacteria, commonly known as blue-green algae, which have been known to cause gastroenteritis, liver damage, and liver failure in humans (Chorus and Bartram, 1999). Depending on the exact species, the algae may be toxic or inedible, causing problems for human health when either water containing dissolved toxins or the cyanobacterial cell itself is ingested (Chorus and Bartram, 1999; World Health Organization, 2005). It has been determined that certain types of algae-produced toxins remain in the processed drinking water despite conventional water treatment; adding urgency to the concern over the inability to predict and prevent the growth of potentially harmful algae (World Health Organization, 2005; Smith and Schindler, 2009).

*Efficacy and Environmental Benefit of Nutrient Reduction Regulations*

Although regulation of nitrogen for the control of eutrophication has only been developed in a few places, regulation of phosphorus concentrations in water bodies is an established practice (Abell, et al., 2010). Successful implementation and enforcement of the TMDLs for phosphorus are necessary for the environmental benefits to be actualized. Among the factors necessary for successfully implementing TMDLs, numeric water quality standards must be measurable, based on the designated use of the water body, and clearly stated (National Research Council, 2001).

It has been noted that the implementation of TMDLs generally has not been as effective as desired due to the uncertainty generated by the slow pace of TMDL development, and in some cases, with little knowledge of the hydrologic systems and inherent water quality the TMDLs were intended to protect (Freedman, et al., 2008). To remedy this, an iterative and more adaptive implementation of TMDLs has been suggested to improve the success rate of water quality restoration (Freedman, et al., 2004; Freedman, et al., 2008). However, regardless of the approaches used, due to a lack of resources, ambient monitoring of waterbodies and data collection across the states is not as uniform or consistent as desired (National Research Council, 2001; Pincumbe, 2012).

However, the desired environmental benefits have recently been achieved when WWTP permits are written on the basis of TP in effluent, as the receiving waters will have a limited amount of bioavailable phosphorus[2] (Lewis, Jr., et al., 2011). Due in part to this, the NPDES permitting system has been credited with contributing to the ultimate goal of improving U.S. water quality (Knopman and Smith, 1993). Building upon this effort, the continued environmental benefit of reducing the pollutant levels from WWTPs can be significant, as researchers have found WWTPs can have a stronger influence on nutrient pollution than non-point sources, such as agriculture (Ahearn, et al., 2005; Popova, et al., 2006).

*Challenges of Regulations on Municipalities*

Municipalities face several challenges when addressing regulations and WWTP permitting with lower permissible levels of nutrients. Among those are an increased pressure on capacity due to development and population growth, the ability to reliably meet the tightened nutrient limit, and the financing required to update and operate the WWTP.

As with other municipal services, increased development and population growth have intensified the pressure on WWTPs. Along with increased budgetary pressure, WWTPs are required to treat a growing quantity of wastewater, which is also increasingly polluted. In many cases, the greater volume of wastewater puts a strain on the capacity of the WWTP, increasing the cost of treatment and the associated energy requirements (Kang, et al, 2009; USEPA, 2008a). Through

[2] Bioavailable phosphorus is the phosphorus which can be readily used by algae. It is usually only a fraction of TP.

USEPA's recent Clean Watershed Needs Survey, it was determined that one of the predominant reasons for requesting funding for wastewater projects was due to population growth (USEPA, 2010).

NPDES permits for specific WWTPs may set the maximum permissible amount of discharged pollutant on a daily, weekly, monthly, and/or annual basis in order to protect the designated uses of the receiving waters. Important in meeting these permit requirements is not just the ability to achieve the discharged pollutant goals, but to do so with a process that is reliable, within the measured timeframe (Kang, et al., 2009). To prevent the WWTP falling out of compliance with the USEPA NPDES permit, WWTP operators must have an excellent understanding of their facility's processes and technologies, including the reliability and efficacy of the processes in removing various pollutants. This knowledge and understanding is critical in adapting the WWTP to fluctuating levels of pollutants found in the wastewater influent and new regulations. When evaluating new or retrofit processes and technologies, municipalities take in to account a variety of factors, including the reliability of the result (USEPA, 2008a; Urgun-Demirtas, et al., 2008).

WWTPs generally need funding for two reasons: meeting new regulatory limits on effluent contaminants and the ongoing maintenance of existing infrastructure. While communities must find funding to attend to nutrient removal upgrades stemming from current or future regulations, they are also faced with an increasingly aging infrastructure in need of repair or replacement (Congressional Research Service, 2010). This is a large enough issue that a substantial portion of the CWA is dedicated to financing WWTPs. Initially, the CWA Title II grants provision made funding available for municipalities to create or expand WWTPs, and between 1970 and 1995, $61.1 billion was paid for the construction of secondary treatment facilities (USEPA, 2011d). Under Title VI in the CWA Amendments of 1987, the Clean Water State Revolving Fund (CWSRF) program replaced the construction grants and established a fund for a variety of water quality projects, including traditional municipal WWTPs (USEPA, 2011e). Through the CWSRF, each state provides low-cost financing for water quality infrastructure projects, including municipal wastewater treatment projects, through a revolving loan fund. In 2003, states were awarded over one billion dollars, and almost five billion dollars was additionally provided to assist wastewater, non-point source, and estuary projects. Ninety-five percent of the CWSRF money is used toward wastewater treatment infrastructure (USEPA, 2008b).

Despite the possible availability of state and federal funding for specific wastewater projects, many municipalities continue to struggle to finance their existing operational costs, not to mention the recommended and required improvement projects. As much as 60 percent of a municipality's energy costs are due to water and wastewater treatment (Law-Flood, 2011). In addition to government grants and loans, additional project funding is collected through user fees, which are becoming increasingly important due to the shrinking availability of governmental funding. In the case of Austin, Texas, residential water and wastewater rates have doubled over the past decade (Austin American-Statesman, 2012). Further complicating matters has been the recent economic downturn and the resulting closure of industrial water users. Because the operational costs of wastewater treatment are mainly fixed, as large industrial water consumers close due to economic pressures, communities must not only cope with the loss of jobs, they also face a loss of water and wastewater fee revenue. In Mount Airy, North Carolina, the closure of several textile factories has increased water and sewer rates by a third, and halted capital improvements since 2008 (Urban, 2010). As the public, in general, has resisted paying more user fees, communities have experienced problems increasing rates with a stagnant or decreasing customer base. In 2011, sewer and wastewater contracting revenue fell 20.7 percent from 2010 (Tulacz, 2012). Without funding, communities are unable to proceed with scheduled or recommended projects.

In an effort to generate the necessary revenue, municipalities are increasingly evaluating ways in which WWTPs may be shifted from solely providing wastewater disposal, to also being a resource provider (Ralston and Ginley, 2010). For example, the Point Loma Wastewater Treatment Plant in San Diego, California uses the methane created in the wastewater treatment process for co-generation of heat and electricity. In a similar case, through the reuse of water for plant maintenance and cleaning, Alexandria Renew Enterprises in Alexandria, Virginia saved almost $3 million in purchased water costs in 2011 (Alexandria Renew Enterprises, 2011).

To ensure the most cost-effective solution to achieving nutrient reductions, some communities are evaluating market-based approaches such as cap and trade.

For example, the 18 WWTPs of the Great Bay Estuary in New Hampshire and Maine are under pressure to significantly reduce the nitrogen in their effluent on a watershed-wide scale (Bresler, 2012). The communities and WWTPs involved in the effort vary greatly in size, which means the costs to upgrade the technologies are not distributed evenly. Small communities may have a larger financial burden than large communities as, due to economies of scale, the unit cost for small WWTPs increases in comparison to the unit cost of larger systems (Daigger, 2004).

Although small communities may prefer on-site treatment to larger, centralized systems, federal aid is generally not available for on-site treatment (Congressional Research Service, 2010). Limited funding may be available for the operation and maintenance of the facility, and when compared with secondary treatment alone, nutrient removal technologies increase the cost of construction by 30-80 percent (Daigger, 2004). In the case of WWTPs within the Great Bay Estuary, a regional pollutant trading program, similar to those of the Acid Rain Program, would not have enough participants to be cost-effective (Bresler, 2012). As a result, many small communities may rely on alternative forms of treatment, such as mechanical, lagoon, or wetland treatment systems, to help achieve lower levels of nitrogen within their discharges (Daigger, 2004; Surampalli, et al., 2007).

*Literature Review Summary*

Overall, the literature documents increasingly stringent regulatory water quality standards related to public and environmental health over the past 40 years. There has also been increasing levels of regulation to achieve lower levels of phosphorus, although this policy goal has been difficult to implement in practice. At the same time, states and municipalities have been challenged by: the capacity to consistently achieve the desired rate of pollutant discharge; increasing population growth; and budget constraints. While the public health effects of phosphorus are still actively being researched, the focus of lowered phosphorus standards has primarily been related to environmental health.

Because of these trends in the research, this study is intentionally focused on the documented challenges to municipalities during data collection. These included interview questions about how WWTP operators dealt with and accommodated population and budgetary challenges. Additionally, during data analysis, particular attention was given to whether actions taken were being driven by public health or environmental concerns.

# Chapter 3

## Research Methods

This chapter describes the methods used to determine how WWTPs address regulations that raise standards to a lower phosphorus tolerance level. The foundation of the research for this thesis is a literature review of journals, books, reports, and articles relating to surface water quality problems, public and environmental health as it relates to phosphorus, and the governmental and community responses to these problems. The literature review provides insight into the history and development of water quality regulation, why phosphorus is a pollutant of focus for freshwater communities, and how communities have resolved the challenges of population growth, reliability of treatment methods, and budgetary constraints.

The results of the literature review serve as a framework for case studies of three municipal WWTPs—Concord, Massachusetts, Parker, Colorado, and Bemidji, Minnesota—and their associated water quality standards. In this instance, case study research is appropriate because the central question being explored is a "how" question. As Yin explains, "case studies are best utilized when a how or why question is being asked about a contemporary set of events over which the investigator has little or no control" (Yin 2003, p. 9). Considering the topic and questions outlined at the start of this thesis, the case study approach is particularly appropriate as the operation of the WWTPs studied, and their regulatory constraints, fall outside the authority of the author, yet the understanding of both are central to the thesis. In addition, the case study approach is appropriate when researching and trying to understand new operations and their impact, as opposed to a singular incidence.

Massachusetts, Colorado, and Minnesota were chosen following a review of the states' status in adopting numeric nutrient criteria for phosphorus, as they represent states in various stages of nutrient criteria development. Massachusetts has site-specific numeric nutrient criteria for nitrogen in estuaries, but is currently developing numeric phosphorus criteria. Colorado has site-specific numeric nutrient criteria for phosphorus in lakes and reservoirs, and is currently developing statewide criteria for both lakes and reservoirs, and rivers and streams. Minnesota has statewide numeric nutrient criteria for phosphorus for lakes and reservoirs, and is developing statewide criteria for rivers and streams.

Locations within the states were identified following a review of publicly owned treatment works (POTWs) phosphorus discharge monitoring data from U.S. EPA's Discharge Monitoring Report Pollutant Loading Tool, and selected following an evaluation of the amount of information publicly available through the Internet. The following locations were ultimately contacted regarding participation in this study:

- Concord Wastewater Treatment Plant, Concord, Massachusetts
- Parker Water and Sanitation District, Parker, Colorado
- Bemidji Wastewater Treatment Plant, Bemidji, Minnesota

Reviewing a limited number of locations allowed for a detailed review of how each location is addressing new regulations with lower phosphorus requirements. This approach was preferred over a broad survey because it allowed for specific regulatory drivers and management responses to be identified.

Each location's and relevant state regulatory authorities' websites and publicly available documents, such as reports written for or by the WWTP facilities, were reviewed to determine the extent to which lower phosphorus criteria requirements are currently being addressed or plan to be addressed. This portion of data collection was primarily Internet-based and included a review of relevant documents, brochures, and management plans, if available. Artifacts were analyzed using a framework developed through information learned from the literature review, in a similar manner to interview data.

Interviews of WWTP operators and employees of the state and federal environmental agencies knowledgeable in each location's nutrient criteria development and water body impairment status informed the case study and verified the information previously collected through Internet research. Individual participants were secured by the researcher, who identified and contacted managers and superintendents of each WWTP with a request for an interview using information found on the facilities' respective websites. Of the three initial contacts, one superintendent referred the request to the operator of the WWTP, and two operators responded affirmatively to the request.

State and federal environmental agency employees were identified either through WWTP operators' responses to an interview question regarding the name of agency employees with whom they interact, or as the authors of the state or federal environmental agency documents or permits pertaining to the WWTP. In total, the seven interviewees listed below in Table 1 contributed to the case studies.

Table 1. Interviewee Names, Positions, and Organizations

| Interviewee | Position | Organization |
|---|---|---|
| **Massachusetts** | | |
| Alan Cathcart | Water/Sewer Superintendent | Concord Public Works, Water and Sewer Division |
| Hardik Raval | Public Works Engineer – Water Systems | Concord Public Works |
| David Pincumbe | Environmental Engineer | U.S. Environmental Protection Agency, Region 1, NPDES Permitting Staff |
| **Colorado** | | |
| Eric Pierce | Water Resources Superintendent | Parker Water and Sanitation District |
| Andrew Neuhart | Assessment-Based Permitting Unit Manager | Colorado Department of Public Health and Environment, Water Quality Control Division |
| **Minnesota** | | |
| Michael Forbes | Co-Superintendent | Bemidji Wastewater Treatment Facility |
| Steven Heiskary | Research Scientist | Minnesota Pollution Control Agency, Environmental Analysis and Outcomes Division |

Interviews were conducted in March, April, and May 2012, with each interview lasting between 40 and 60 minutes. They were conducted by phone both due to geographic considerations, as well as for purposes of consistency. Interview questions were informed by the literature review, and designed to seek information on topics including:

- Wastewater management challenges and prioritization at specific facilities
- How phosphorus reduction was addressed in current planning and management efforts
- Efforts taken to reduce the phosphorus levels in the influent
- The level of compliance with past and current NPDES permits
- Need and status of technology evaluation for the further removal of phosphorus
- Additional information or resource needs to increase capacity to address lowered phosphorus requirements
- Funding mechanisms used for new processes or technologies

In addition to the initial interview guide, each interview served as input into the development of the interview guides for the subsequent interviews. The Tufts University Institutional Review Board granted this study an exempt status (see Appendix A).

# Chapter 4

## Case Studies

This section presents three case studies of WWTPs within states with different requirements regarding discharging phosphorus in the effluent. First, I will share the case study of Concord Wastewater Treatment Plant in Concord, Massachusetts, which is currently struggling with population growth. Next, I present the Parker Water and Sanitation District case study from Parker, Colorado, and their efforts towards reducing phosphorus in their effluent. Finally, I review the case of Bemidji Wastewater Treatment Facility in Bemidji, Minnesota, which initially began reducing the phosphorus in its effluent due to economic concerns related to the environmental health of its receiving waters.

*Case 1: Concord Wastewater Treatment Plant, Concord, Massachusetts*

The Town of Concord, Massachusetts is located 20 miles west of Boston, Massachusetts. Approximately 35 percent of the Town's 17,668 residents are served by the sewer collection system (Ellis and Cathcart, 2008; United States Census Bureau, 2010). The sewer system was originally established in 1900, and currently comprises 33 miles of sewer collection pipelines, two sewer pumping stations, six sewer lift stations, and one centralized WWTP.

In the early 1900's, wastewater treatment in Concord consisted of pumping water from a collection system in downtown to open fields with natural filtration. The system has had various improvement phases, including an Imhoff tank designed to partially remove solids during the 1950s, before an enhanced secondary treatment facility was constructed in 1986 using funding available from the federal and state governments (Cathcart, 2012). In 2007, the WWTP upgrades included a new sludge dewatering process, a tertiary treatment system for the removal of phosphorus, and a switch from chlorine to ultraviolet disinfection. The WWTP schematic for the plant can be found in Appendix B.

Since its construction in 1986, the WWTP (Figure 2), which is permitted for up to 1.2 million gallons per day (MGD), discharges treated effluent to the Concord River, north of the confluence of the Assabet and Sudbury Rivers (Figure 3). As the Assabet River is listed on the Massachusetts 303(d) list of impaired waters and is listed within Category 5, which are waters requiring a TMDL, of the Massachusetts Integrated List of Waters,[3] the Commonwealth has developed a TMDL for TP. The Sudbury River has been listed in the Massachusetts Integrated List of Waters as Category 5, and in need of a

Figure 2. Concord WWTP
Source: H. Raval, Concord WWTP

[3] The CWA Section 303(d) requires states to submit a list of waters that do not or are not expected to meet water quality standards with the implementation of technology-based controls to USEPA for approval on even-numbered years. Once a waterbody has been placed on the 303(d) list of impaired waters, states have eight to thirteen years to provide a long-term plan for completing TMDLs to address each pollutant causing impairment. The CWA Section 305(b) requires states to submit a report on the health of all waters. As most states have used the 305(b) report when developing the 303(d) list, USEPA has recommended states combine the reports to create an "Integrated Report."

TMDL for metals. The Concord River is also listed on the Massachusetts 303(d) list of impaired waters and is listed within Category 5 of the Massachusetts Integrated List of Waters, in part due to nutrients.


Figure 3. Location of Concord Wastewater Treatment Plant, Concord River, and Assabet River
Source: Google Earth

Throughout Massachusetts, phosphorus pollution is increasing. As noted by USEPA Region 1 Environmental Engineer David Pincumbe, “Phosphorus is absolutely a statewide problem. It’s a rare river system that doesn’t have a phosphorus problem” (Pincumbe, 2012). Although Massachusetts has developed a site specific numeric criterion for nitrogen in some estuaries, there is no statewide numeric criteria for phosphorus. The Massachusetts Surface Water Quality Standards contains the following narrative standard:

> Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and [best available technology (BAT)] for non POTWs, to remove such nutrients to ensure protection of existing and designated uses (Massachusetts Surface Water Quality Standards, 2007).

As one of five non-delegated states in the country, in Massachusetts, NPDES permits are developed by the USEPA Region 1 office, and then the Massachusetts Department of Environmental Protection (MassDEP) certifies that the permit is stringent enough to meet their standards. At USEPA, the NPDES permits that restrict phosphorus pollution are typically being addressed for the protection of aquatic life, not for public health. However, as David Pincumbe indicated, “if there is a water supply intake downstream, there can be issues with phosphorus enrichment and drinking water. But generally the levels that we’re regulating to protect aquatic life are usually also addressed in the problems of drinking water” (Pincumbe, 2012).

The Concord WWTP has been treating its effluent for phosphorus for 15 years, three NPDES permit cycles (Cathcart, 2012).The most recent NPDES permit, which are valid for five years following the effective date, for the Concord WWTP was issued in 2006 and the site is currently in the review process for a new permit. The 2006 Concord WWTP NPDES permit listed a phosphorus limit of 1.0 milligrams per liter (mg/L) for November through March, and an interim seasonal phosphorus limit of 0.75 mg/L for April through October, with a new seasonal phosphorus limit of 0.2 mg/L beginning April 2009. Since approximately 1998, the Town of Concord had been aware that lower phosphorus tolerance levels were being considered by USEPA that could affect the course of its wastewater treatment in the future. For this reason, in 1999, the Town undertook a collaborative trial of a phosphorus reduction technology with the technology's developers, which, following an evaluation in 2003 of alternative phosphorus removal options, ultimately led to the technology's integration into the design and construction of a full-scale tertiary treatment system (Ellis and Cathcart, 2008). During the period of evaluation, the Town was notified by USEPA that the upcoming 2006 NPDES permit would have a 0.2 mg/L phosphorus limit, which allowed the evaluation to more precisely estimate the costs associated with phosphorus reductions to that level (Ellis and Cathcart, 2008).

While at the time of my interviews, the facility had not seen a draft of the new permit, each new permit tends to reduce the level of phosphorus the facility is allowed to discharge. Alan Cathcart, Concord Water/Sewer Superintendent, noted that "every permit cycle is a new opportunity for the regulators to review the best practical treatment" (Cathcart, 2012). The negotiation of what the USEPA would like to limit the discharge to, and what the Town of Concord is able to afford could take months or years, depending on the differences between the two parties (Cathcart, 2012). Despite statewide numeric criteria for phosphorus being in development, the facility does not expect the statewide criteria to have a large effect as the Concord WWTP is already operating under one of the state's more stringent levels of phosphorus discharge.

While the Concord WWTP has directed resources towards the reduction of phosphorus and process improvements, one of the greatest challenges it faces is due to its capacity and the permitted flow of 1.2 MGD. Due to the Concord's concerns regarding growth, when the facility was designed and built in the mid-1980s, it was deliberately and strategically "right-sized" for the time (Cathcart, 2012). Over the past decade, the WWTP has been increasingly strained by trying to meet the needs of areas in Concord where septic systems are not adequate. In addition, there has been a recognition that the current capacity is not sufficient to execute the housing and economic goals outlined in the Town's 2004 *Planned Production Housing Plan*, 2005 *Comprehensive Long Range Plan*, and the Village Center Committee's vision for the future (Town of Concord, 2009).

A few of the objectives of the Town's Wastewater Task Force were to determine how much wastewater flow was associated with the desired new development, what portion of this flow can be accommodated by the town, and how Concord can fund design and construction costs related to any future municipal wastewater management solutions (Town of Concord, 2011a). Since the non-delegated state status necessitates working with both MassDEP and USEPA, which can be lengthy and complex on its own, a challenge has been how to maintain the existing NPDES permit and avoid needing to request an increase in the permitted flow volume (Cathcart, 2012). Since the NPDES permit is currently being drafted, the Concord WWTP is planning to request an increase in flow within the comments of the draft permit; this request is purely in anticipation of the future need, as the town is not likely to exceed its existing permit of 1.2 MGD in the next two years. The hydraulic capacity of the current WWTP could be increased with a relatively small capital investment (Town of Concord, 2011b).

As with many municipalities, Concord's WWTP must make difficult decisions while navigating budgetary pressures. To ensure that the "operation, maintenance, and capital improvement of the sewer system would be a financially viable enterprise" the 1976 Annual Town Meeting established a Sewer Fund. Using the Sewer Fund, expenses for the WWTP system are covered entirely by user fees. As of June 30, 2010, the total value of collection system and WWTP infrastructure assets was approximately $25.9 million (Town of Concord, 2011c). The plant construction and upgrades in the 1980s were 90 percent covered by federal and state money, but the approximately $15 million upgrades in 2007 were covered by a state revolving loan fund with a two percent interest rate and by an increased user fee from roughly 1,500 users (Cathcart, 2012).

The Public Works Commission sets the sewer rates each year following a public hearing. The commission strives to balance the need to ensure sufficient resources for the Sewer Division, with the need to minimize rate "shock" for users in a way that is a predictable expense and accurately reflects sewer usage (Town of Concord, 2011c). In each year since fiscal year (FY) 2008, user fees have increased approximately 5 percent, for an overall increase of 21.5 percent. During the same time frame, WWTP operating expenses have increased 19.1 percent, and expenses for supplies and materials have increased 35.7 percent. These expenses do not include capital costs sustained by projects designed to increase the lifespan of the WWTP by an additional twenty years. Despite increasing sewer rates, the Sewer Division anticipates operating revenues will only cover approximately 94 percent of operating expenditures for FY 2012. It is not until FY 2017 that the projected operational expenses decline enough to have a positive operating income (Town of Concord, 2011c).

*Case 2: Parker Water and Sanitation District Wastewater Treatment Plant, Parker, Colorado*

The Town of Parker, Colorado, which is situated 20 miles southeast of Denver, Colorado, incorporated in 1981 with 285 people and one square mile of land (Parker Planning Commission, 2009). As of 2010, the town has grown to a population of 45,297 within its approximate 18.8 square mile area (United States Census Bureau, 2010). The residents are primarily served by Parker Water and Sanitation District's (PWSD) 64.8 miles of sewer pipelines, with one pump station, one lift station, and two centralized WWTPs.

Figure 4. PWSD North WWTP Administration Building
Source: E. Pierce, PWSD

PWSD's South WWTP was built in the early 1980s as a typical activated sludge plant. Subsequent the Colorado Department of Public Health and the Environment (CO DPHE) Water Quality Control Commission's adoption of Regulation 72[4] in 1985, the Plant was modified to include biological nutrient removal and filtration, as well as chemical addition (Pierce, 2012). Following tremendous population growth between 1990-2010, which caused strain on the South Plant, the North Plant (see Figure 4) came online in 2004 with technology similar to the existing South Plant providing secondary and advanced treatment of the wastewater. In both plants, the water is treated with the chemicals aluminum sulfate and ferric chloride in order to precipitate phosphorus to achieve their permitted level. The WWTP schematic for the plant can be found in Appendix B.

The combined 2.7 MGD North and South WWTPs discharge effluent through a combined outfall to Sulphur Gulch, which is not currently listed as impaired (Figure 5). The discharge point is approximately 20 feet from Cherry Creek, which has as an "undesignated reviewable" antidegradation designation from the CO DPHE (Pierce, 2012). The designation indicates that the water is "to be maintained and protected at [its] existing quality unless it is determined that allowing poorer water quality is necessary to accommodate important economic or social development in the area" of the water (Colorado Department of Public Health and the Environment [CO DPHE], 2001). However, algal growth attributable to high levels of chlorophyll α in the Cherry Creek Reservoir, which is located approximately 10 miles north of the confluence of Sulphur Gulch and

[4] Regulation 72, the Cherry Creek Reservoir Control Regulation, was adopted to control point and nonpoint sources of nutrients to protect the quality and uses of Cherry Creek Reservoir.

Cherry Creek, resulted in the Reservoir's impairment listing on Colorado's 2008 303(d) List of Water-Quality-Limited Segments Requiring TMDLs.


Figure 5. Discharge point for PWSD into Sulphur Gulch and Cherry Creek
Source: Google Earth

As recognized by the adoption of Regulation 72 in 1985, phosphorus levels have been a concern within the Cherry Creek Watershed for over 25 years. The Regulation, which focuses on phosphorus, relies on the actions of the state, for example, for permit limits, and local regulation of nonpoint sources to protect the water quality. Using a watershed-based approach, Regulation 72 contains phosphorus point source effluent limitations for industrial process wastewater sources, domestic wastewater facilities, reclaimed water use authorizations, and drinking water treatment facilities, in addition to nonpoint source and individual sewage disposal system nutrient controls, stormwater permit requirements, and nutrient monitoring requirements (CO DPHE, 2010). The effect of the controls set by Regulation 72 have possibly resulted in Colorado's removal of the Cherry Creek Reservoir from its 2012 303(d) List of Water-Quality-Limited Segments Requiring TMDLs.

However, phosphorus remains a problem throughout the state, not only in the Cherry Creek Watershed. To address the increasing level of phosphorus pollution throughout Colorado, the Water Quality Control Division in the CO DPHE began the work group process for developing statewide numeric nutrient criteria for nitrogen and phosphorus (i.e., adopting a new section within Regulation 31) in 2001, and regulating nutrient discharges (i.e., adopting Regulation 85) in 2010 (USEPA, 2012). The Water Quality Control Commission, the administrative agency responsible for developing specific state water quality policies, has recently held a rulemaking hearing for the finalization of a new section in the Basic Standards and Methodologies for Surface Water, Regulation 31, which establishes interim numerical values for phosphorus, nitrogen, and chlorophyll α. The new Nutrients Management Control Regulation, Regulation 85, amongst its provisions, establishes numerical effluent limitations for domestic wastewater treatment plants. Colorado has established its approach as "necessary to protect the public health, beneficial uses of Colorado waters, and the environment of the state" (CO DPHE, 2012a).

Although both Regulations are in the final stages of being adopted, they will not become effective until September 2012. As of May 15, 2012, the Water

Quality Control Commission had reopened the rulemaking hearing to receive comments on a proposed delay in the effective date and a potential exemption of domestic facilities smaller than 1.0 MGD from the numeric effluent limitations in Regulation 85 (CO DPHE, 2012b).

As a delegated state, CO DPHE develops NPDES permits for USEPA's approval. The NPDES permits are valid for approximately five years, and may be administratively extended following expiration before a new permit can be in place. A new system currently being implemented will align permit cycles for all permits within a given river basin after the basin has been reviewed by the Commission. Doing so will allow any new or revised standards to be implemented much sooner than if the permit cycles were scheduled independently (Neuhart, 2012).

At CO DPHE, although NPDES permits that limit phosphorus discharges are being addressed for both environmental and public health purposes, the primary driver is environmental concern. One of the significant issues with excess nutrients is algae growth and the associated problems for aquatic life. As other standards, such as nitrate, are more applicable than phosphorus for drinking water uses, NPDES permits tend to have more of a focus on aquatic life. However, as Andrew Neuhart, Assessment-Based Permitting Unit Manager at CO DPHE noted, "if a reservoir or stream is used for a drinking water intake, the drinking water treatment facility would need to remove the algae" (Neuhart, 2012).

The most recent NPDES permit for the PWSD WWTPs was effective December 14, 2011. The permit had changed from the previous version in that the

North and South plants were formerly treated as a combined plant due to the combined effluent outfall. In addition, the previous permit seasonally grouped months together for a maximum phosphorus concentration, where the current permit treats each month individually in terms of the maximum phosphorus concentration.

As PWSD is within the Cherry Creek Reservoir Watershed, their NPDES permit reflects the phosphorus discharge limits specified by Regulation 72. Prior to 2001, Regulation 72 specified that NPDES permits for effluent were not to exceed 0.2 mg/L phosphorus for industrial process wastewater and wastewater facilities, including the PWSD's North and South WWTPs. In 2011, the monthly average of the PWSD WWTPs for the year was 0.025 mg/L phosphorus, which is below the 0.05 mg/L phosphorus level that had been stipulated by their NPDES permit since 2001 (Pierce, 2012). In the last ten years, the facility has not been out of compliance regarding phosphorus in its effluent. During that same time period, infrequent violations due to chlorine and pH levels were addressed by establishing standard operating procedures to ensure the proper tests are completed (Pierce, 2012).

Following the potential adoption of a new section in the Basic Standards and Methodologies for Surface Water, Regulation 31 and new Nutrients Management Control Regulation, Regulation 85, the PWSD does not expect any changes regarding limits of phosphorus in effluent to effect their operations (Pierce, 2012). Firstly, the numeric limits of the new Regulations will not be included in NPDES permits of dischargers subject to Regulation 72 prior to May

31, 2022. Secondly, Regulation 85 currently lists the numeric criteria for domestic wastewater treatment facilities of 1.0 mg/L annual median phosphorus, which is less stringent than the level at which the PWSD WWTPs have been operating.

As a relatively new community, the population growth has been tremendous. In the early 1980s, when the PWSD South WWTP was built, Parker's population was approximately 300 people (Parker Planning Commission, 2009). Between 1990 and 2000, Parker grew 332 percent, and by 2000, the population had grown to approximately 23,000 people (Parker Planning Commission, 2009). To address the strain on the South WWTP, the North Plant was constructed. Although growth slowed 2008-2010 due to the economic recession, continued growth is expected, and a full build-out of the community would lead to an estimated 115,000 people (PWSD, 2012a; PWSD, n.d.). To handle the expected growth, the 2012 PWSD budget allows for the creation of a fund reserve that would be applied towards future WWTP expansion costs (PWSD, 2012b). Although the sewer rates remain static for 2012, the increasing cost of wastewater management was cited as a potential future concern (Michlewicz, 2012).

The most significant management challenge the PWSD WWTPs are currently facing is balancing the cost of phosphorus removal with the level of removal. The advanced treatment provided by the biological nutrient removal activated sludge system reduces the incoming 6.5-7 mg/L to less than 0.5 mg/L, but the remainder of the reduction is achieved chemically. While the phosphorus level has been brought down to 0.015 mg/L, more chemical addition was necessary, and consistency was an issue. As Eric Pierce, Water Resources Superintendent indicated, "the driving force behind phosphorus removal is the chemical addition necessary to get levels down to 0.05 mg/L—and there are a lot of associated costs. Probably two-thirds of the plants' cost goes into chemicals" (Pierce, 2012). WWTP operating expenses have increased almost 15 percent since 2009, with the cost of supplies increasing 2.6 percent.

*Case 3: Bemidji Wastewater Treatment Facility, Bemidji, Minnesota*

The City of Bemidji, Minnesota is centrally situated in northern Minnesota, approximately 200 miles north of Minneapolis, Minnesota. Approximately 50 percent of the City's 13,431 residents are served by the Bemidji sewer collection system (Forbes, 2012; United States Census Bureau, 2010). The system is composed of 99 miles of sewer collection pipelines, 31 lift stations, and one centralized WWTP.

Bemidji's wastewater treatment system began in the early 1900s, and was upgraded to a primary sedimentation tank in the 1930s (Forbes, 2012). The current centralized WWTP (Figure 6) was built following hydraulic capacity overloading problems, and began operating in

Figure 6. Bemidji WWTF
Source: M. Forbes, Bemidji WWTF

1985. In addition to rehabilitation of the primary clarifier in 2006, only routine maintenance and repair of the existing system has occurred over the last 27 years. The first major modification to the facility is the currently ongoing construction of an additional primary digester, which is designed to better control total suspended solids (TSS) and biochemical oxygen demand (BOD) levels (Forbes, 2012). The WWTP schematic for the facility can be found in Appendix B.

The City of Bemidji's WWTP is the first major wastewater discharging facility on the Mississippi River, and, as seen in Figure 7, discharges to the quarter mile segment of the Mississippi River located between Lake Irving and Lake Bemidji (Forbes, 2012). The area has a strong dependence on both Lake Irving and Lake Bemidji for tourism. In the 1970s, prior to the current facility's WWTP, in an effort to maintain the water quality of Lake Bemidji, the discharge point was moved to the Mississippi River at the Lake's discharge point. Although Lake Bemidji's water quality improved, the river and lakes downstream began deteriorating, triggering the newly formed Minnesota Pollution Control Agency (MNPCA) to address the phosphorus levels that it determined were the root cause (Forbes, 2012). Among the various methods to resolve the water quality problem, Bemidji built the current WWTP with a focus on phosphorus removal, and changed the discharge point to its current position between Lake Irving and Lake Bemidji.

Figure 7. Bemidji WWTF, Lake Irving, Mississippi River, and Lake Bemidji
Source: Google Earth

Although the phosphorus concentration within the portion of the Mississippi River to which the facility currently discharges is within a range that is acceptable for the Mississippi River's characteristics, large portions of the River, including where it discharges into the Gulf of Mexico, have extreme issues directly related to phosphorus levels (Heiskary, 2012). For example, Lake Pepin, in southern Minnesota near the Wisconsin border, was listed in Minnesota's 2004 303(d) Impaired Waters List for excessive nutrients. It is so heavily polluted that it has suffered from algal blooms and severe fish kills, especially during low-flow years with less than average precipitation (Metropolitan Council Environmental Services, 2002). In its Lake Pepin Site Specific Eutrophication Criteria, the MNPCA noted that "the main biological activity affecting Lake Pepin trophic status is not taking place in the lake, but upstream of it" (Minnesota Pollution Control Agency [MNPCA], 2011).

Water quality has been an issue within Minnesota for many years. The MNPCA first adopted water quality standards in 1967, and has had narrative criteria describing unacceptable characteristics of water since the 1970s. In the mid-1980s, the state began exploring the development of nutrient standards and looking at lakes using an ecological region framework (Heiskary, 2012). That work led to the development of phosphorus criteria that provided initial thresholds for the conditions of the lakes in the early 1990s, and ultimately resulted in statewide numeric standards for phosphorus and two indicators of eutrophication that measure the response of lakes to excess phosphorus in 2008 (MNPCA, 2008a). Specific numeric nutrient standards are applied to lakes based on the ecological regions within the state and a classification system based on four different types of lakes. The standards require point source dischargers of sewage to remove phosphorus at least to a level of 1 mg/L (MNPCA, 2008b).

Since 2008, the MNPCA has continued to develop numeric standards for phosphorus in relation to rivers. Steven Heiskary, Research Scientist at MNPCA, noted that,

> "Part of [developing the river standards] is you're developing the science and science is not as well established. In the case of lakes, the linkages were more straightforward and more readily available in the literature, and so [MNPCA] had to do similar things for rivers. [MNPCA] had to understand the region's patterns in nutrients, the cascading effect of nutrients in a flowing water system, and what an excess of nutrients might mean or how that might impact it biota" (Heiskary, 2012).

In November 2010, the Minnesota Nutrient Criteria Development for Rivers draft was published and is also included in the 2008-2012 Triennial Water Quality Rule Review. Both the numeric criteria for lakes, and those being developed for rivers, are intended to protect public health from an aquatic recreation perspective, and environmental health from the standpoint of aquatic life (Heiskary, 2012).

As Minnesota is a delegated state, USEPA reviews and approves NPDES permits developed by MNPCA. The permits are valid for approximately five years, and are typically reviewed following an assessment of the watershed. Multiple factors are reviewed prior to development of a NPDES permit, including the determining if the receiving water body fully supports its uses, any impairment determination, and any completed TMDLs for the water body, including any allocations for the wastewater facilities (Heiskary, 2012).

The NPDES permit limit for the Bemidji WWTF is an example of an early water quality based effluent limit within Minnesota, where the limit was determined based upon what could be discharged and still ensure protection for Lake Bemidji (Heiskary, 2012). The Bemidji WWTF has operated under a 0.3 mg/L phosphorus effluent limit NPDES permit since its new facility began operating in 1985. Despite the possible promulgation of numeric standards for phosphorus in relation to wastewater discharges to rivers, changes to the NPDES permit are not anticipated when the current permit expires in November 2014 (Forbes, 2012). As the statewide criteria is expected to be less stringent than the Bemidji WWTF’s current operations, a continued 0.3 mg/L discharge limit NPDES permit is expected.

In general, the facility has maintained compliance; however, in 2009, the monthly average was exceeded one time during a period of upset within the plant. The laboratory used for determining the phosphorus levels in the effluent began reporting high levels to the facility, which indicated to the WWTF operators that the facility was experiencing a level of upset. The facility attempted to measure the phosphorus levels using their plant's processes to enable a quicker reaction, but needed to rely upon the data reported from the laboratory ten days to two weeks following submission of samples. During this time, the laboratory reported an extremely high phosphorus level, which was enough to raise the monthly average of the facility above the permitted limit. According to Mike Forbes, Co-Superintendant of the Bemidji WWTF, to resolve the high phosphorus levels, the facility raised chemical levels and adjusted the process "as well as we could within the bounds of what we were able to do, and the process improved and the levels went back down" (Forbes, 2012). A definitive explanation for the high phosphorus levels was never established, and since that incident, the WWTP has not been out of compliance.

Population growth within the sewage system is not currently a concern within Bemidji. The demands of an increasing population were one of the drivers necessitating the construction of the current facility; however, most of the growth in the years since has occurred outside of the area served by sewer lines (Forbes, 2012). Although the WWTP has an average wet weather design flow of 2.5 MGD, since it began operating, it has maintained a 1.0 MGD average.

Like many municipalities, the City of Bemidji and the WWTP must operate within budget constraints. Operating expenses increased approximately 3.8 percent per year from 2001 to 2009. During mid-2008, the City requested the facility undergo some restructuring in an effort to cut costs. Staffing was reduced from eight people, to five people, and from 16 hours to eight hours a day during weekdays and from ten hours to four hours a day on weekends. An alarm system is set up to alert the operators to anomalies during the un-staffed times. In addition, the certified laboratory that the WWTP operated was closed, while a contract laboratory has been used since for all analysis of water samples. The laboratory's closure is the largest factor in the delayed response to higher phosphorus levels in the effluent. Prior the facility's certified laboratory's closure, results for phosphorus levels were available the same day, whereas results from the contract laboratory are received ten days to two weeks later. The staffing changes and laboratory closure resulted in an annual decrease of $100,000 in operating expenses.

Other significant management challenges the Bemidji WWTF is facing are increased levels of TSS and BOD, as well as operational and maintenance costs associated with aging infrastructure. In general, the facility has very good to adequate control of the effluent phosphorus levels. While the influent averages 10-11 mg/L, in 2010, the facility's effluent had an average phosphorus concentration of 0.14 mg/L, sufficiently below the NPDES permit level of 0.3 mg/L. However, since 1985, the TSS and BOD levels have doubled over the design capacity of the WWTP (Forbes, 2012). As the rise is attributed to an increase in restaurants and food waste, the facility expects to address the problem, in part, through public education regarding materials in the waste stream (Forbes, 2012).

The Bemidji WWTF was designed with a 20 year lifespan when it was built in the mid-1980s. As the plant continues to operate past its anticipated lifespan, many updates are anticipated in the near future to bring the facility in line with treatment processes found at newer and more efficient WWTPs (Forbes, 2012). For example, although the aeration system works well, it is very energy intensive compared with fine bubble diffusers. In addition, while solids handling is being addressed through the new digester under construction, rehabilitation of the current storage digester or construction of a new storage digester may be necessary for efficiency. Finally, maintenance of the current systems continues to be an ongoing issue as parts age and fail, some of which are too old to find a source for replacement (Forbes, 2012).

# Chapter 5

## Cross-Case Analysis and Conclusions

Looking across the case study sites, several overarching themes are evident in relation to the research questions: (1) actions taken by regulators are primarily guided by concern for the environment; (2) population growth and funding are concerns for the municipalities, but addressed differently and to varying degrees; and (3) despite differences in the method of regulation within the facilities' respective states, facilities were able to successfully respond to policy mandates and employ strategies to lower phosphorus discharge levels. Each of these will each be explored below, and followed with several implications for future research and practice in the area of phosphorus reduction and control in wastewater facilities.

*Environmentally-Driven Actions*

In each case study, the environmental agency charged with developing NPDES permits–USEPA for Concord, Massachusetts, CO DPHE for Parker, Colorado, and MNPCA for Bemidji Minnesota–indicated phosphorus discharge limits were addressed primarily as a matter of environmental health; specifically, the environmental health of aquatic life.

However, although environmental health was mentioned as the most important factor, each case study did also mention that public health issues were considered. It was noted in Colorado that other regulations or standards may be more applicable to phosphorus levels in drinking water, but if the receiving water body was used as a drinking water source, public health concerns became a factor in addition to aquatic life health. Similarly, USEPA Region 1 indicated that phosphorus enrichment in drinking water would be addressed, but they are generally dealt with by the existing drinking water regulations. However, in Minnesota, the numeric criteria regulations specifying the lower phosphorus tolerance level for lakes, and the regulations currently in progress for rivers, are designed to protect the public health through aquatic recreation.

At two case study sites, Concord WWTP and PWSD WWTP, the wastewater treatment operators indicated they felt the lower phosphorus tolerance level regulations under which they operate were driven by environmental health concerns. At the Bemidji Wastewater Treatment Facility, the operator believed economic reasons related to tourism and recreation were the primary factor. It was thought that the motivation for the initial NPDES permit for the wastewater facility was the desire to restore Lake Bemidji and other water bodies in the area to a cleaner state to re-establish and preserve tourism.

Despite some public health concerns, environmental concerns regarding phosphorus levels were the primary focus for the case study sites. Environmental health concerns prevailed largely because there are no known problems with phosphates in drinking water, so the public health issues arise primarily from aquatic recreation, which is both tied to and less notable than protecting aquatic life. From the perspective of the WWTPs, environmental health concerns prevail over public health as their focus is on meeting regulatory compliance, which are almost exclusively targeted at environmental health concerns.

*Population Growth and Revenue Challenges*

Population growth and revenue challenges were cited at each of the case study sites; however, the sites differ in how the growth was incorporated and funded during the design and construction of the WWTPs. One of the Concord WWTP's current concerns is its present capacity and its ability to operate within its NPDES permitted flow amount. Although the facility was purposefully designed to meet the capacity at the time of construction, it was strategically planned to handle a limited amount of growth. Previous planning efforts by the Town have resulted in a relatively static population since 1990. However, the Town's current vision of the future now requires a certain amount of housing and economic growth, which the WWTP cannot process. In order to resolve the capacity problem, the WWTP will request an increase in permitted flow during the comment phase of the upcoming NPDES permit process; however, this is only a partial solution, as the facility will need to obtain additional capital investment to handle any increased capacity. While Concord has had an established Sewer Fund to cover WWTP system expenses entirely through the collection of user fees, the operating expenses are not anticipated to cover expenditures until FY 2017, despite increases in user fees. Further, this budget estimate does not take in to account any capital expenditures that the system may incur before that date.

Similar hydraulic capacity concerns were a factor in the design and construction of both the PWSD WWTP and Bemidji WWTF. The Town of Parker, Colorado grew at such a tremendous rate that the South Plant needed to be augmented with the construction of the North WWTP. Fortunately, the construction and growth were anticipated, with user fees from an increasing number of households and businesses helping to reduce the amount of the loan needed, but it did not offset the cost entirely. Despite significantly slowed growth due to the recent economic recession, the operating revenues are higher than operating costs. However, planning for increased growth and the necessary WWTP expansion has continued with the establishment of a fund reserve to apply towards the required WWTP expansion costs.

Similar to Concord, Bemidji addressed the potential for population growth through municipal planning. However, unlike Concord's desire to limit growth, Bemidji encouraged and anticipated a continued increase in population, planning accordingly in the design of the WWTP. Although the City's population has grown since construction of the WWTP, it has largely occurred outside of the sewer system, so expansion of the WWTP is not required. Despite not incurring the capital costs of expansion, the facility has still been challenged due to the municipality's budget constraints. The facility has reduced staffing and the hours of staffed operation, and restructured plant operations to eliminate their laboratory at the request of the City.

Consequently, while all three case study sites experienced challenges due to population growth and revenue, the manner in which each site dealt with these concerns during WWTP construction is directly related to their current capacity. The sites that anticipated and planned for continued growth, PWSD and Bemidji WWTF, have either the current, or planned, hydraulic capacity to handle the associated growth's wastewater. However, while PWSD does have the planned capacity, the necessary funding for the expansion project(s) is currently being established. Participants also indirectly spoke to the reasons behind the rising costs, including: the rising costs of chemicals for treating the wastewater; increased volume of wastewater needing treatment; increased quantity of waste in the wastewater; and operational and maintenance costs due to aging infrastructure, as most WWTPs were built for a 20 to 30 year lifespan.

*Facility Response to Policy Mandates*

The WWTPs struggled less with raised standards to a lower phosphorus tolerance level than previous research would imply. Both PWSD WWTP and Bemidji WWTF designed and constructed new facilities that would meet the NPDES permits which specified lower permissible levels of phosphorus in their effluent. The Concord WWTP was the only site whose facility was operating under a NPDES permit with a higher permissible level of discharged phosphorus before being required to operate at within a lower tolerance level due to a subsequent NPDES permit. However, the Town was aware of the possibility of more stringent standards with respect to phosphorus; the USEPA notified the WWTP of the NPDES permit limit prior to issuance, and the NPDES permit gradually lowered the phosphorus to below the desired tolerance levels. This phased approach allowed the facility time to design and construct the processes necessary to ensure compliance with the lowest tolerance level specified.

Similarly, each case study site's respective state is in a different stage of statewide regulation, but none of the facilities studied will be affected as they are already operating below the state limits. Although Massachusetts has established site-specific numeric nutrient criteria for nitrogen in estuaries, the numeric nutrient criteria for phosphorus is still in development. However, site specific standards are developed as a part of the TMDL program. Since the Concord WWTP is already operating under one of the state's more stringent levels of phosphorus discharge, the facility does not anticipate a statewide numeric criteria at a lower level.

Colorado has developed site-specific numeric nutrient criteria for phosphorus in lakes and reservoirs, one of which applies to the Cherry Creek Reservoir Watershed, where the PWSD WWTP operates and discharges. The state is also currently developing statewide criteria for both lakes and reservoirs, and rivers and streams, but the PWSD WWTP does not expect the phosphorus tolerance levels of the statewide criteria to effect their operations as the site-specific criteria of Regulation 72 is lower than the proposed statewide criteria, and with the facility currently operating well below even the site-specific levels.

Minnesota has already implemented statewide numeric nutrient criteria for phosphorus in lakes and reservoirs, and is presently developing criteria for rivers and streams. Despite the proximity to Lake Irving and Lake Bemidji, the Bemidji WWTF officially discharges to the Mississippi River, so the promulgated statewide criteria for lakes and reservoirs does not apply. Similar to the situation in Colorado, the Minnesota statewide criteria for rivers and streams is not expected to have an impact on the Bemidji WWTF operations as the statewide criteria is expected to be less stringent than the NPDES permitted levels under which the facility has operated since 1985.

Each of the case study sites struggled with the new regulations less than anticipated due to previous research. While the Concord WWTP required facility changes to comply with a raised standard to a lower phosphorus tolerance level, the PWSD WWTP and Bemidji WWTF, where the facilities were built intentionally to comply with lower phosphorus tolerance levels, were able to successfully attack this issue through typical plant processes. Due to their success in addressing their current stringent phosphorus discharge limits, none of the sites expects statewide regulation to affect their operations.

*Recommendations and Conclusions*

Expanding on the information noted in the literature, the findings indicate that population growth and funding concerns are challenges that apply to all WWTPs, regardless of the geographic location. The case study sites demonstrated that overcoming population growth concerns is possible through coordinated planning efforts with the municipality to ensure that both community leaders and the public sewer system are working towards mutually identified goals. Similarly, in agreement with the literature and recent news reports, results indicate revenue challenges are increasingly apparent across all municipalities and their WWTPs.

Although solutions are specific to the individual location, these findings indicate resolutions which incorporate cost reduction through facility process efficiencies with continual short- and long-term resource planning reducing the reliance on incurring debt.

According to the U.S. Department of Labor, Bureau of Labor Statistics, the consumer price index, a measure of the cost of living, has not increased more than 4% in any given year since 1991. However, as seen in Concord, Massachusetts, increases in user fees have repeatedly exceeded these increases in the consumer price index. Similarly, each study site experienced increasing operational expenses at a rate greater than cost of living adjustments. These increases in user fees are a common response to the problem of WWTPs facing reduced revenue; however, the case studies have shown that residents and businesses will apply increasing amounts of pressure on community and WWTP officials to reduce costs and generate revenue by alternative means. This supports results within the literature that the public has resisted paying more user fees, resulting in the municipality experiencing problems increasing rates with a stagnant or decreasing customer base. A possible solution to the problem involves increasing the public awareness of the costs of sewer system operations and maintenance, as well as public education regarding the waste stream, wastewater treatment processes, and the environmental benefits/clean water resulting. Increased public awareness and education has the potential to benefit the WWTP in multiple ways. First, the public would gain a greater understanding of their role in creation of wastewater, possibly leading to a decreased volume of wastewater needing treatment, alleviating hydraulic capacity and energy consumption concerns. Secondly, a reduction in the amount of pollutants and solids needing removal from the wastewater influent would result in further reduced operating costs for the facility.

As noted in the literature, the nexus between wastewater treatment and human health is drinking water or contaminated food. As a result, regulating phosphorus discharges from municipal wastewater facilities does not directly address the problem in the same manner as other regulations, which are specifically geared towards protecting human health through drinking water and food. If the current public health regulations involving drinking water and/or food are failing, perhaps the problem could be addressed through WWTP phosphorus discharges after examining the costs and benefits of a variety of non-regulatory and regulatory methods. However, assuming the current drinking water regulations continue to be successful in protecting human health, there is no need for redundant regulation.

Ultimately, findings from the interviews, analysis of relevant state regulatory authorities' websites, and publicly available documents indicate that WWTPs have struggled to overcome obstacles relating to population growth and ongoing funding concerns, while simultaneously working within regulatory mandates from both state and federal agencies to meet lower levels of phosphorus in their effluent. The WWTPs have been successful through a combination of careful planning and coordination with the municipalities, as well as their active participation in the permitting process of the state and federal regulatory agencies.

Working closely with their municipalities has allowed the WWTPs to both plan for, and execute, their expansion as the number of users has grown, as well as manage cost when municipality budgets have decreased. At the same time, participating in, and commenting on, the regulatory permitting process has allowed the WWTPs to receive advanced notice about stricter regulations, and in some cases, a phased approach to the regulations, allowing the WWTPs time to reach compliance with the lower phosphorus levels.

### *Limitations and Future Direction*

This thesis was intended to review a small sample of WWTPs regarding their approach towards achieving mandated lower phosphorus discharge limits and the obstacles they faced. As such, it was not designed to be representative of a large population, but rather a detailed review allowing for specific regulatory drivers and management responses to be acknowledged. Though there are several limitations to the research conducted within this thesis, those mentioned below are primarily related to the participant selection process and the limited scope of the thesis.

While the three case study sites presented were appropriate given the selection criteria, an additional level of understanding regarding conformance to new and stricter phosphorus regulation could have been gained by including sites that were, or have been, out of compliance with their NPDES permit. In addition, the sampling methods previously described made it difficult to represent all of the relevant stakeholder groups in the area affected by each WWTP. Although interviews were conducted with the appropriate WWTP staff and affiliated environmental agency employee, interviews with additional stakeholders or partner organizations were not attempted. Future research to include these perspectives would allow for a more complete look at the wastewater system. However, despite the exclusion of additional stakeholders and partner organizations, the data collected remains pertinent to the scope of this thesis.

The collection and treatment of stormwater was not addressed in this thesis. It is unknown if any of the sites treat stormwater with the collected residential, business, and industrial wastewater. Based on land use composition, additional research could explore the extent to which phosphorus contributions come from stormwater runoff. Furthermore, a review of the cost effectiveness of separating stormwater from traditional wastewater could be investigated. Finally, nutrient control technologies were not the focus of this thesis; future research could evaluate current, emerging, and innovative technologies for the cost effective removal of phosphorus.

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## Appendix A

Tufts UNIVERSITY

OFFICE OF THE VICE PROVOST

Social, Behavioral, and Educational Research
Institutional Review Board
FWA00002063

Title: Phosphorus Control at Wastewater Treatment Plants

February 23, 2012 | Notice of Action

IRB Study # 1202042 | Status: EXEMPT

PI: Katherine Moore
Faculty Advisor: Sheldon Krimsky
Review Date: 2/23/2012

The above referenced study has been granted the status of Exempt Category 2 as defined in 45 CFR 46.101 (b). For details please visit the Office for Human Research Protections (OHRP) website at: http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.html#46.101(b)

- The Exempt Status does not relieve the investigator of any responsibilities relating to the research participants. Research should be conducted in accordance with the ethical principles, (i) Respect for Persons, (ii) Beneficence, and (iii) Justice, as outlined in the Belmont Report.
- Any changes to the protocol or study materials that might affect the Exempt Status must be referred to the Office of the IRB for guidance. Depending on the changes, you may be required to apply for either expedited or full review.

IRB Administrative Representative Initials: LNS

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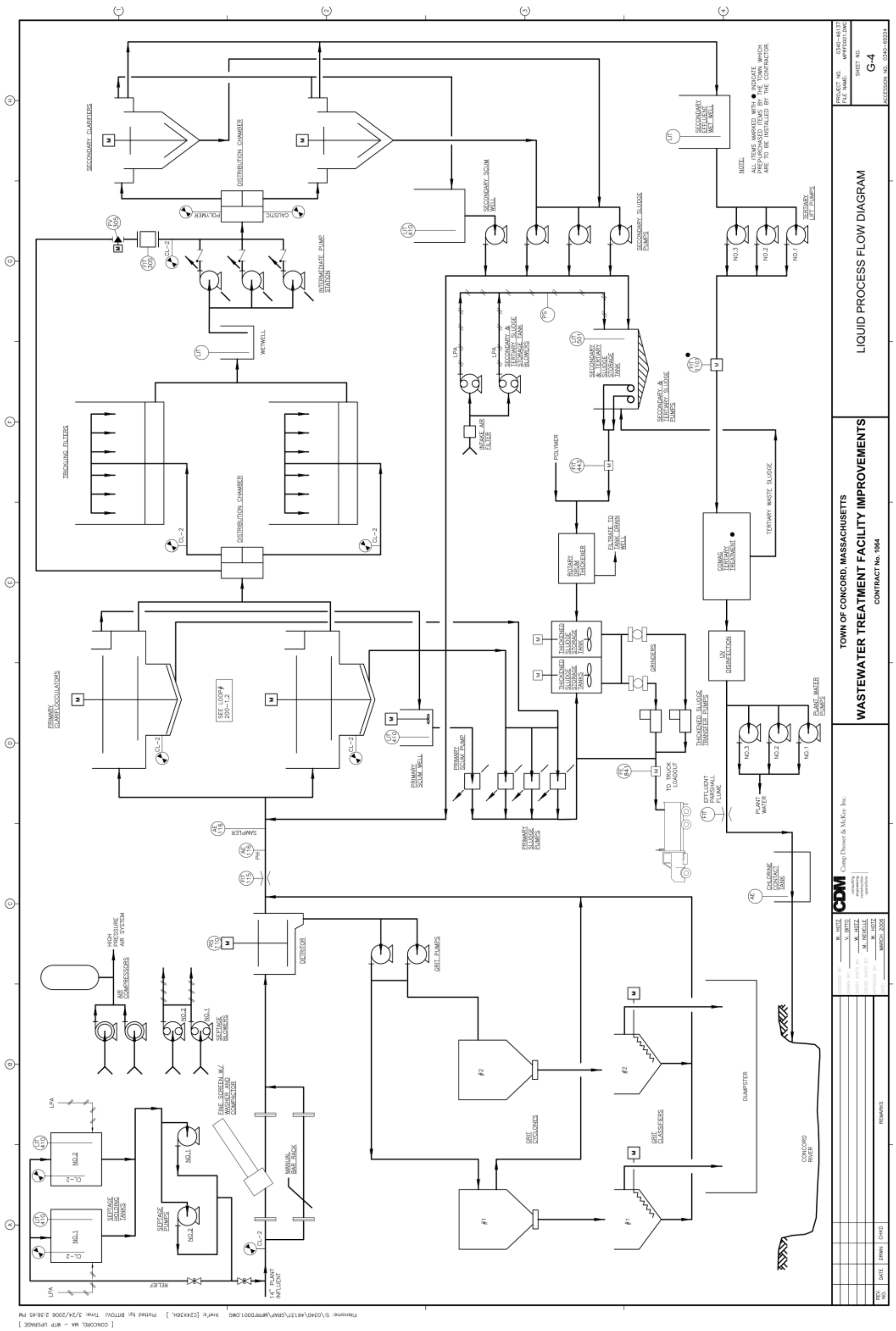
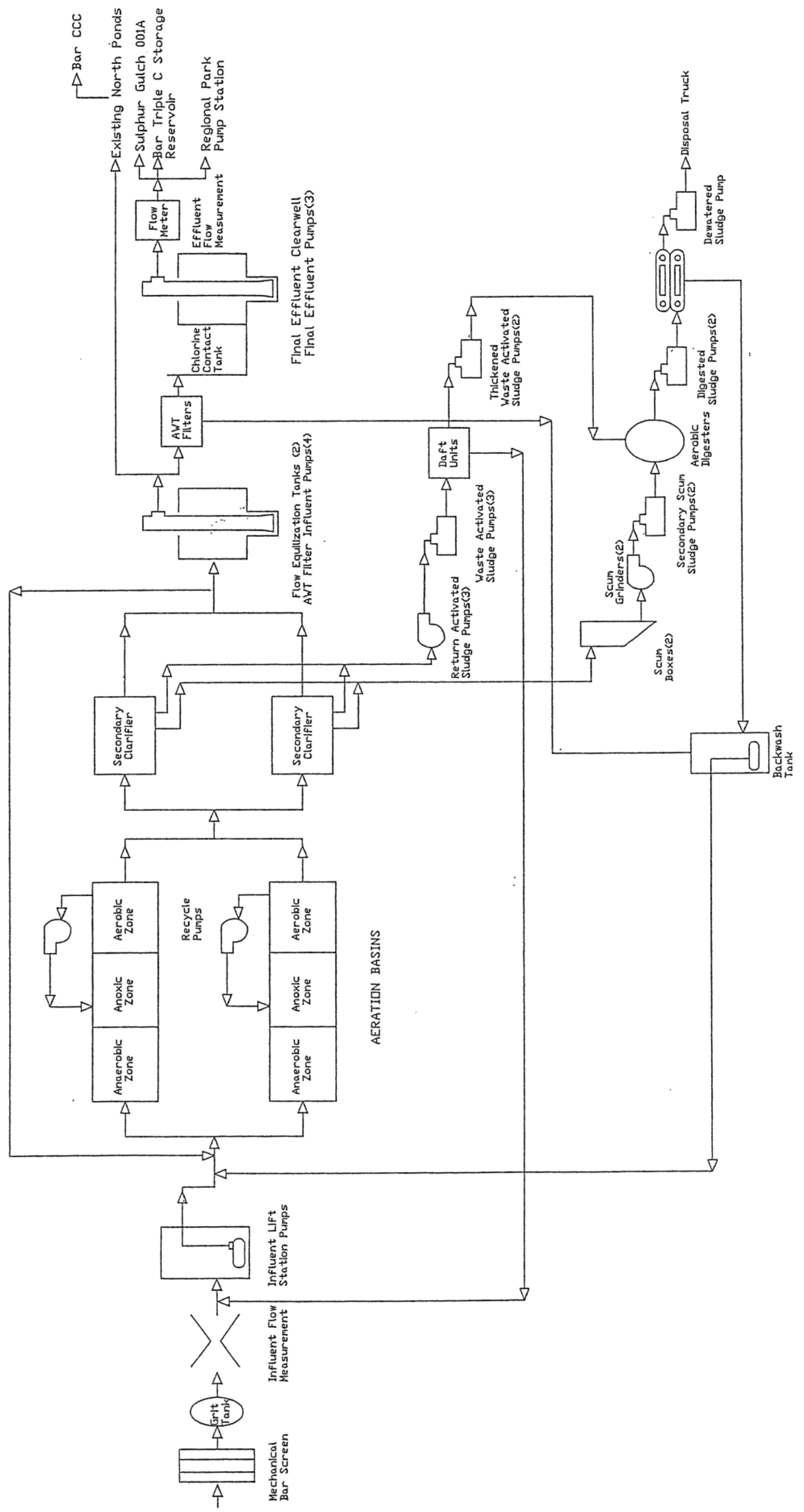
# Appendix B

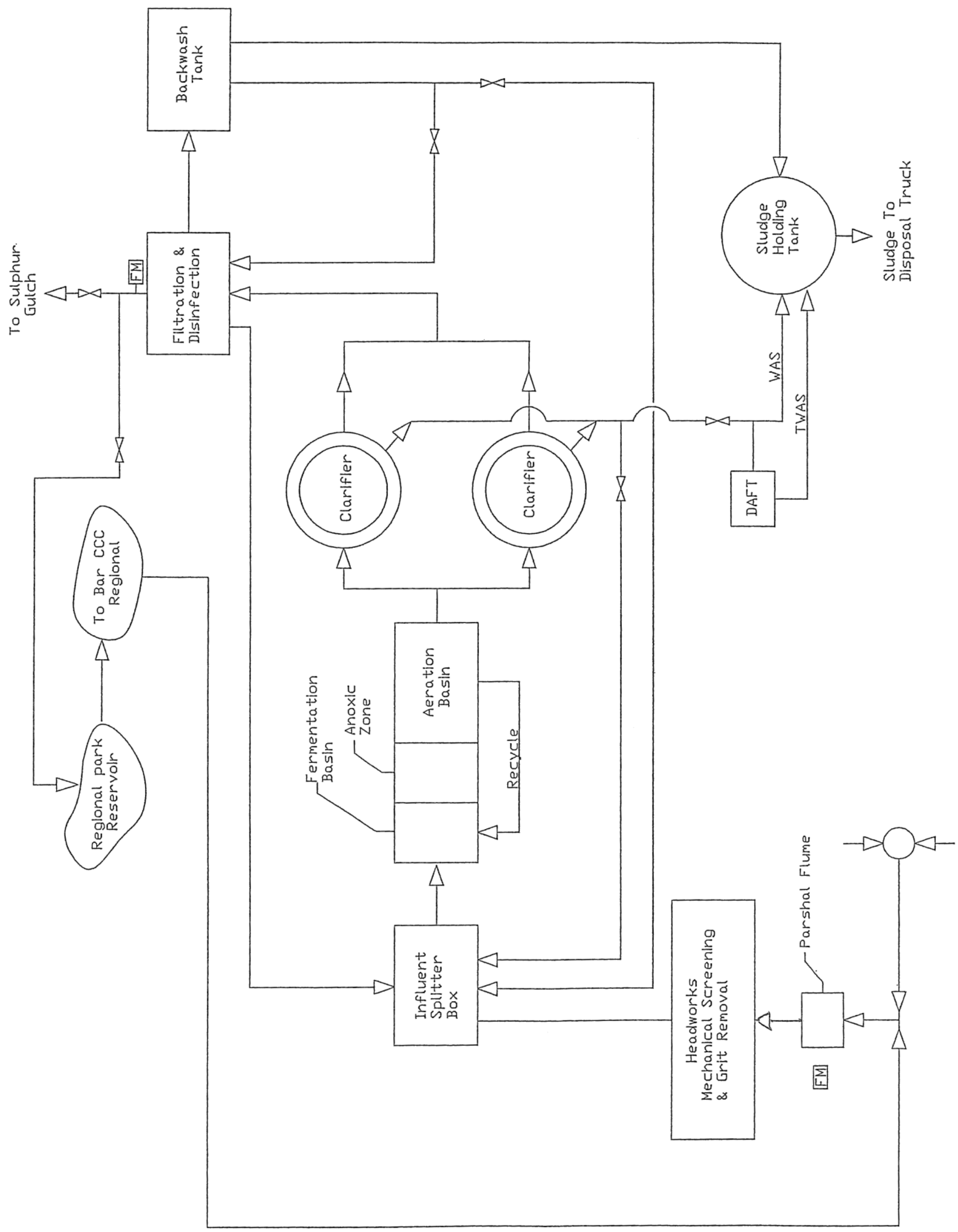
Concord Wastewater Treatment Plant Treatment Diagram



Parker Water and Sanitation District North Wastewater Treatment Plant Diagram



Parker Water and Sanitation District South Wastewater Treatment Plant Diagram



Bemidji Wastewater Treatment Facility Diagram