3.6 Effluent Total Phosphorus Reduction Efforts by Wastewater Treatment Plants

As discussed in Section 2.2.4, several WWTPs were contacted regarding phosphorus treatment methods at their plant. The WWTPs were asked to identify the total flow into the plant, unit operations at the plant, phosphorus treatment method, influent and effluent phosphorus concentrations, estimated costs for phosphorus treatment, and methods used for limiting phosphorus input to the WWTPs. The WWTPs ranged in size (0.7 to 24 million gallons per day), treatment methods (chemical and/or biological phosphorus removal), and phosphorus discharge requirements (0.07 mg/L to 2.41 mg/L). All of the WWTPs surveyed were activated sludge plants. This section summarizes the findings of the WWTP surveys, for a more detailed description of each WWTP see Appendix L. Phosphorus removal performance data for each of the WWTPs surveyed are presented in Table 3-20. Average wet weather design flow (AWWDF) and additional information regarding significant industrial users (SIUs) are included in Table 3-20 and Appendix L, respectively. Pond systems were not evaluated for this study, but it should be noted that pond systems are capable of removing phosphorus by batch chemical treatment prior to controlled discharges.

Four of the eight WWTPs used chemical treatment only for phosphorus removal. The chemicals used were either alum or ferric chloride. The WWTPs are described below in order from the lowest total phosphorus discharge requirement (0.3 mg/L, Bemidji, MN) to the highest (2.41 mg/L, Mankato, MN):

- The Bemidji WWTP is the first WWTP discharge into the Mississippi River, just upstream of Lake Bemidji. A phosphorus effluent limit of 0.3 mg/L total phosphorus or less is required as part of the NPDES permit. To meet the NPDES requirements, the WWTP uses alum for phosphorus precipitation and polymer for suspended solids precipitation. The alum and polymer are added after the activated sludge aeration basin but before the secondary clarifier. The average total phosphorus concentration entering the plant is 7 mg/L and the average total phosphorus concentration discharging from the plant is 0.15 mg/L. Bemidji does not have any significant industrial users, so the phosphorus entering the plant is primarily from domestic sources. This system has an average flow of 1.15 MGD. Costs for phosphorus removal were based solely on alum costs. A treatment cost of $3.25 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

- The St. Croix Valley WWTP discharges into the St. Croix River/Lake St. Croix at Oak Park Heights, Minnesota and is one of the WWTPs operated by the Metropolitan Council. A phosphorus effluent limit of 0.8 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses alum for phosphorus precipitation. The alum is added at the inlet to the primary clarifier. The average total phosphorus concentration entering the plant is 4.8 mg/L and the average total phosphorus concentration discharging from the plant is 0.45 mg/L. This system has an average flow of 3.4 MGD. Costs for phosphorus removal were based solely on alum costs. A treatment cost of $0.96 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

- The Rochester WWTP discharges into the Zumbro River upstream of Lake Zumbro. A phosphorus effluent limit of 1 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses ferric chloride and alum for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added to the primary clarifier and alum and polymer are added to the secondary clarifier. The average total phosphorus concentration entering the plant is 7.5 mg/L and the average total phosphorus concentration discharging from the plant is 0.7 mg/L. Rochester has several significant industrial users that discharge to the WWTP. Daily maximum and monthly average total phosphorus limits are set for significant industrial users to limit the phosphorus discharged to the WWTP by industry. This system has an average flow of 14 MGD. A treatment cost of $1.76 per pound of phosphorus removed was given by the Rochester Environmental Coordinator. Since no further description of the treatment costs was given, it was assumed that treatment costs were based solely on chemical costs.

- The Mankato WWTP discharges to the Minnesota River at Mankato. A phosphorus discharge cap of 20,000 kg/yr (2.41 mg/L at 6 MGD) of total phosphorus is required as part of the NPDES permit, with a phosphorus discharge goal of 15,700 kg/yr (1.89 mg/L at 6 MGD). To achieve the NPDES effluent limits, the WWTP uses ferric chloride for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added at the influent of the WWTP and is settled out in the primary clarifier. Polymer is added to the secondary clarifier for solids precipitation. The average total phosphorus concentration entering the plant is 8.0 mg/L and the average total phosphorus concentration discharging from the plant is 1.88 mg/L. This system has an average flow of 6 MGD. Mankato has several significant industrial users (SIUs) that discharge to the WWTP. SIUs are allowed to

discharge 1 kg/day of total phosphorus, which is averaged on an annual basis, at no charge. Any discharge above this loading is charged a fee. The fee is based on the treatment costs and phosphorus treatment efficiency for the year and includes chemical costs, biosolids disposal, maintenance, utilities, and lab analysis. Capital costs are not included. The treatment cost is approximately $1.70 per pound of phosphorus removed ($3.75 per kg). In comparison, the cost for phosphorus removal using chemical costs alone was $0.70 per pound of phosphorus removed. The all-inclusive costs are 2.3 times greater than the chemical only costs. This was the only facility in the survey that provided more inclusive costs for chemical phosphorus removal.

Four of the eight WWTPs used enhanced biological phosphorus removal (EBPR). In addition to EBPR, three of the four plants surveyed also use chemical treatment to meet total phosphorus discharge requirements below 1 mg/L. The WWTPs are described in order from the lowest total phosphorus discharge requirement (0.07 mg/L, Durham and Rock Creek WWTPs, Oregon) to the greatest (monitoring only, St. Cloud). Listed below is a brief description of the WWTPs that used EBPR:

- The Rock Creek and Durham WWTPs are located just west of Portland, Oregon in the Tualatin Watershed and have one of the lowest phosphorus discharge requirements in the United States of approximately 0.07 mg/L total phosphorus. The average flow for the Durham WWTP is approximately 20 MGD and the Rock Creek WWTP is 24 MGD. The average total phosphorus influent concentration is 7 mg/L for both plants. Each WWTP has a mass-based monthly median total phosphorus discharge of 9 lb/day (0.07 mg/L total phosphorus based on the average flow rate for each plant) during the summer (May – October). The Rock Creek and Durham WWTPs use EBPR and two-point alum addition to meet the stringent 0.07 mg/L total phosphorus discharge requirement. Pilot testing and full scale system modifications were required to reach the high level of phosphorus removal achieved by these plants. Alum is added to the primary clarifier prior to EBPR, total phosphorus concentrations after alum treatment in the primary clarifier and EBPR are approximately 0.5 mg/L. After the first alum treatment and EBPR, alum is added to the secondary clarifier; the effluent from the secondary clarifier is then filtered for an average total phosphorus effluent concentration of 0.05 mg/L. Prior to implementing EBPR, the Durham facility only used chemical treatment (alum) for phosphorus removal. Significant cost savings were observed once enhanced biological phosphorus removal was implemented at the Durham facility (i.e., the chemical costs for alum were cut by one third). Chemical

costs for the facility are now approximately $0.47 per pound of total phosphorus removed. The pilot test and plant modifications to achieve EBPR at the Durham facility cost approximately $900,000. Because of the public awareness of phosphorus discharge into this sensitive watershed, industries have voluntarily reduced phosphorus discharges.

- The Ely WWTP discharges into Shagawa Lake. The NPDES discharge requirement is 0.3 mg/L total phosphorus. EBPR and chemical addition of alum are used to meet the NPDES discharge requirements. The average annual flow into the WWTP is approximately 0.7 MGD. Lime had originally been used at the Ely plant for chemical precipitation, but because of the high cost associated with lime treatment, the plant switched to alum. When EBPR does not meet the discharge requirement alum is added to the mixing zone of the secondary clarifier. The secondary clarifier effluent is then passed through sand filters; the final total phosphorus average effluent discharge concentration is 0.2 mg/L. For short periods of time, the WWTP has been able to achieve 0.05 mg/L total phosphorus discharge concentrations. It was estimated by the WWTP superintendent that the costs associated with phosphorus removal are approximately 25% of the annual operating budget. Therefore, the estimated cost for phosphorus treatment is approximately $20 per pound of phosphorus removed. This WWTP does not have any significant industrial users discharging to the WWTP; therefore, the phosphorus source is primarily from domestic dischargers. Phosphorus influent to the plant was significantly reduced in the early 1980's by educating the public on limiting the use of phosphorus in detergents. As estimated by the WWTP superintendent, the total phosphorus influent to the WWTP was reduced from 12 to 15 mg/L prior to public education to approximately 5 mg/L after public education.

- The St. Cloud WWTP uses EBPR for phosphorus removal. The discharge from this WWTP is into the Mississippi River at St. Cloud. This WWTP was not initially designed for EBPR. In 1996 the City of St. Cloud modified the existing wastewater treatment plant to improve energy efficiency by replacing the coarse air diffusers in the aeration basin with fine air diffusers. In addition to the energy efficiency improvements, the WWTP was modified for EBPR by installing an anaerobic zone in the first pass of each aeration tank. The average flow into the WWTP in 2002 was 10.6 MGD and the average total phosphorus influent in 2002 was 5.0 mg/L; after EBPR the average effluent total phosphorus is 0.93 mg/L. The St. Cloud WWTP NPDES discharge permit requires monitoring of effluent total phosphorus and development and implementation of a phosphorus management plan. The City of St. Cloud implemented a Phosphorus Management Plan (PMP) in 2001, with a primary goal of limiting

the amount of phosphorus coming into the facility by means of pollution prevention and public outreach. The goal of the pollution prevention program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads. The city works with industrial users to keep phosphorus discharges to the WWTP below 6 mg/L. This method is effective at reducing spike loads and the average influent phosphorus concentrations. Comparing the 95% confidence limits of the average influent phosphorus concentrations prior to implementation of the PMP (7.72 mg/L ± 1.22 mg/L, 2000) to the 95% confidence limits of the average influent phosphorus concentrations after implementation of the PMP (5.03 mg/L ± 0.14 mg/L, 2002), there has been a significant reduction and less variability in the average phosphorus influent concentration. The lowering and stabilization of the influent total phosphorus concentration is also credited in decreasing the average total phosphorus effluent concentration from 2.01 mg/L in 2000 to 0.93 mg/L in 2002.

The following discussion summarizes the conclusions of the aforementioned survey done to evaluate phosphorus reduction efforts by wastewater treatment plants:

- The cities implementing source reduction programs all achieved significant reduction in phosphorus loading on their WWTPs using a variety of methods: public outreach, phosphorus bans, surcharges for phosphorus treatment, and maximum limits on SIU phosphorus discharges.

- The St. Cloud WWTP showed that a reduction in influent phosphorus loading and phosphorus slug loads lead to a reduction in effluent phosphorus concentration.

- Chemical treatment is capable of reaching the lowest phosphorus effluent concentrations.

- The cost per unit of total phosphorus removed varied from $0.96 to $20.00 per pound of total phosphorus removed. Some of this variation appears to be the result of various cost calculation techniques. The cost of treating phosphorus chemically appeared to show an economy of scale.

- The cost for chemical treatment was lower for those WWTPs that used a combination of EBPR and chemical treatment.

- EBPR alone is generally effective at achieving 0.5 mg/L to 1 mg/L effluent phosphorus concentrations. Chemical addition is necessary to achieve effluent phosphorus concentrations less than 0.5 mg/L. One of the best available bio/chemical treatment facilities (Durham WWTP, OR) was able to achieve an average effluent phosphorus concentration of 0.05 mg/L. To reach this low effluent concentration, significant pilot testing was required and phosphorus removal efficiency was dependent upon wastewater characteristics.

- Once the initial capital improvements are made there are no additional costs associated with phosphorus removal using EBPR.

- In some cases EBPR can be implemented with simple process modifications (e.g., St Cloud aeration modifications) that achieve reductions in effluent phosphorus concentrations. St Cloud was able to achieve an effluent phosphorus concentration of 0.93 mg/L with this approach.

It should also be noted that the data used for this study is from the years 2001, 2002 and the first half of 2003. During that time period many POTWs (Blue Lake, Seneca and quite a few other cities) have implemented phosphorus removal or will begin to implement it in the future.

As population growth occurs, and POTW flows increase, if effluent concentrations remain constant there will be corresponding increases in total phosphorus loadings.

Table 3-20 Wastewater Treatment Plant Phosphorus Removal Summary

Treatment Plant	Treatment Method	Average WWDF (MGD)	Average Flow (MGD)	TP Influent (mg/L)	Average TP Effluent (mg/L)	Treatment Cost	Total Phosphorus NPDES Requirement
Ely	EBPR and alum after activated sludge and before secondary clarifier when necessary and sand filtration	3	0.7	5	0.2	$20/lb All inclusive	0.3 mg/L
Bemidji	Alum & polymer after activated sludge and before secondary clarifier	2.5	1.15	7	0.15	$3.25/lb TP Chemical only	0.3 mg/L
St. Croix Valley	Alum in primary clarifier inlet	5.8	3.4	4.8	0.45	$0.96/lb TP Chemical only	0.8 mg/L
Mankato	Ferric chloride at influent and polymer at belt filter for sludge dewatering	11.25	6	8	1.88	$1.70/lb TP all inclusive $0.74/lb Chemical only	20,000 kg/yr (cap) = 2.41 mg/L TP at 6 MGD and 15,700 kg/yr (goal) = 1.89 mg/L at 6 MGD
St. Cloud	EBPR	26	10.6	5.03	0.93	NA	ND
Rochester	Ferric chloride in primary; alum & polymer in secondary	19.1	14	7.5	0.7	$1.76/lb TP Chemical only	1 mg/L
Durham WWTP (Tigard, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	20	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow
Rock Creek (Hillsboro, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	24	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow

Key:
EBPR = Enhanced Biological Phosphorus Removal
NA = Not Available
MGD = Million Gallons per Day
TP = Total Phosphorus
ND = Not Determined