Evaluation of Exemplary WWTPs Practicing High Removal of Phosphorus

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This memorandum was prepared to provide information regarding the performance of exemplary wastewater treatment plants (WWTPs) practicing high removal of phosphorus to assist in determining effluent phosphorus concentrations that are achievable with current wastewater treatment technologies. The Technology Work Group for the Spokane River TMDL identified a number of exemplary WWTPs that were practicing high removal of phosphorus and achieving effluent total phosphorus concentrations of 50 μg/L or less. Nine WWTPs were selected from this group and detailed evaluations were performed. The nine WWTPs were selected based on size, technologies utilized and confidence that the effluent data were reasonable. A tenth WWTP, Breckenridge, Colorado was added because the information became available and it represented potentially the lowest effluent phosphorus concentration of the entire group. The 10 plants were (from largest to smallest):

- Las Vegas, Nevada
- Alexandria, Virginia
- Rock Creek (Portland area), Oregon
- Durham (Portland area), Oregon
- Cauley Creek (Atlanta area), Georgia
- Lone Tree (Arapahoe County), Colorado
- Walton, New York
- Iowa Hill (Breckenridge), Colorado
- Pinery, Colorado
- Stamford, New York

Two years of daily effluent total phosphorus data were obtained for each WWTP and the log normal average and coefficient of variation were calculated for each year. The data for each WWTP were used without modification except to correct obvious data entry errors. The log normal average was used because the log normal distribution typically fits the data better than a normal distribution. The log normal coefficient of variation (COV) is a simple numerical representation of the variation of data. A larger COV indicates greater variation

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of daily data. Graphs of annual daily data and the log normal average for each WWTP illustrate the variation of the daily data.

Preliminary analyses of the short-term, small-scale pilot studies of phosphorus removal at the City of Spokane River Park Water Reclamation Facility (RPWRF) are also presented for information. Small-scale pilot studies have been performed using Parkson DynaSand D2 Filtration, US Filter Microfloc Trident and Zenon Membrane Filtration technologies and they provide information on what effluent concentrations of total phosphorus may be possible for the City of Spokane. Each pilot has operated for approximately 1 month.

The effluent concentrations are presented in terms of μg/L and mg/L. There are 1,000 μg/L in 1 mg/L. To convert from mg/L to μg/L, multiply by 1,000. The following are examples of the conversion:

0.10 mg/L = 100 μg/L

0.05 mg/L = 50 μg/L

Summary of Results

Table 1 summarizes the evaluation of full-scale exemplary WWTPs practicing high removals of total phosphorus. Factors that appear to be associated with effluent phosphorus concentrations at the exemplary plants include effluent permit limits, treatment plant size, treatment technology, method of solids processing, and the availability of a sufficient number of qualified operators and staff. Another factor that may affect the observed performance is the frequency of sampling and laboratory analytical considerations. Larger WWTPs had higher effluent phosphorus permit limits, had higher effluent phosphorus concentration and included anaerobic digestion. It is not possible to determine cause and effect from the information gathered. While associations exist between effluent phosphorus concentration, effluent phosphorus permit limits, plant size and anaerobic digestion it is not possible to determine which are causative, the magnitude of causative effect and which are just coincidental. The effluent phosphorus concentrations based on the actual daily data for the majority of WWTPs was significantly higher than the information produced by the Technology Work Group for the Spokane River TMDL appeared to show. Plants of substantial size (>2.5 mgd) had similar effluent performance with both chemical clarification followed by media filtration, and membrane bioreactor (MBR) with chemical addition. The larger plants reviewed in this investigation had daily 24-hour composite effluent monitoring and were measuring phosphorus concentrations greater than 25 μg/L. The amount of effluent data is greater and daily sampling of 24-hour composite samples ensures that process variability is well documented. The higher concentrations of effluent total phosphorus require less stringent quality control in the laboratory and are less subject to variation in laboratory analysis. This adds confidence to the reported phosphorus concentration in the effluent.

Exemplary plants reporting the lowest effluent phosphorus concentrations in the range of 8 to 46 μg/L were relatively small (<2.5 mgd), had lower effluent phosphorus limits, had newer phosphorus removal technologies, had limited solids processing and limited sampling and effluent testing. These associations also do not prove cause and effect and it is

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not possible to determine which factors are causative and most significant. The results from the smaller WWTPs suggest that the larger WWTPs using new phosphorus removal technologies may be able to achieve these lower effluent total phosphorus concentrations. However, the effects of plant size and solids processing must be determined from full-scale operation to confirm if this is indeed feasible. Effluent sampling and laboratory analysis may also significantly affect the apparent performance of the smaller WWTPs. Most of the smaller WWTPs sampled once per week or as little as twice per month. One did not use 24-hour composite samples. The result is the number of effluent data are much less and the potential exists that process variability is not captured with the reduced sampling. The effluent phosphorus concentrations are much less and there is evidence (see later section) that laboratory methods for measurement of phosphorus concentrations less than 25 μg/L are subject to substantial variability. The result of the limited sampling and challenges of measuring low concentrations of total effluent phosphorus is reduced confidence in the reported effluent total phosphorus concentrations for the smaller WWTPs.

The substantially sized treatment plants evaluated in this investigation (> 2.5 mgd) are more comparable to most of the facilities discharging to the Spokane River. These larger facilities are achieving effluent total phosphorus in the range of 71 to 179 μg/L total phosphorus. Notable plants of substantial size employing chemical clarification and media filtration that have performance in this range include the Rock Creek (34 mgd) and Durhman (25 mgd) plants in Oregon. The 5 mgd membrane bioreactor plant (MBR) at Cauley Creek, GA also has effluent phosphorus performance in this range.

The Rock Creek and Durham plants have one of the most restrictive phosphorus limits at 100 μg/L. Rock Creek has achieved effluent total phosphorus concentration of 71 and 82 μg/L over the phosphorus removal season of May to October in 2004 and 2005. Similarly, the Durham plant has achieved effluent total phosphorus concentration of 102 and 73 μg/L over the phosphorus removal seasons in 2004 and 2005. Rock Creek total effluent phosphorus has increased from 48 to 57 μg/L for the years 2001, 2002 and 2003. The recent increase in effluent phosphorus at Rock Creek and Durham is attributed to an increase in effluent total phosphorus concentration in the NPDES permit which now allows monthly median total phosphorus in their effluent of 100 and 110 μg/L, respectively. Less alum is required to be added to meet the less stringent NPDES permit and this saves the wastewater utility money.

All of the exemplary plants examined had data points well above and below the mean. This variability may be related to a variety of conditions that have not been fully assessed in this analysis (process changes, upset, chemical feed, temperature, level of operator experience, etc.) which may, or may not be controllable. For these reasons, permit limits based on a long-term averaging period, such as seasonal averaging, appears essential to successful compliance with phosphorus effluent levels less than 100 μg/L.

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TABLE 1
Summary of Exemplary WWTPs in U.S. Practicing High Phosphorus Removal

Facility	Average Design Flow (mgd)	Recent Average Flow (mgd)	NPDES Total Phosphorus Limit (µg/L)	Final Effluent Log Normal Average Total Phosphorus (µg/L)		Coefficient of Variation of Final Effluent Total Phosphorus		Liquids Process	Solids Process
				Year 1	Year 2	Year 1	Year 2		
Las Vegas, Nevada	91	63	170	179	152	0.28	0.52	30-mgd biological nutrient removal, trickling filters and activated sludge for remainder, blended followed by filtration	Thickening, anaerobic digestion and dewatering.
Alexandria, Virginia	54	40	Month 180, week 270	134	88	0.76	0.48	Ferric chloride primary clarification, activated sludge, ferric chloride secondary clarification, alum chemical clarification, multimedia filtration	Pasteurization, anaerobic digestion and dewatering
Rock Creek (Portland area), Oregon	34	32	Month median 100 May 1 through October 31	82	71	0.48	0.47	Alum primary clarification, activated sludge secondary, alum-chemical clarification, alum - multimedia filtration	Anaerobic digestion and dewatering
Durham (Portland area), Oregon	25	17	Month median 110 May 1 through October 31	102	73	1.01	0.65	Biological nutrient removal with alum addition to primary, secondary and chemical clarifiers followed by sand filtration	Fermentation of primary sludge, thickening of waste activated and chemical sludges, anaerobic digestion of primary and waste activated sludge and dewatering

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TABLE 1
Summary of Exemplary WWTPs in U.S. Practicing High Phosphorus Removal

Facility	Average Design Flow (mgd)	Recent Average Flow (mgd)	NPDES Total Phosphorus Limit (µg/L)	Final Effluent Log Normal Average Total Phosphorus (µg/L)		Coefficient of Variation of Final Effluent Total Phosphorus		Liquids Process	Solids Process
				Year 1	Year 2	Year 1	Year 2		
Cauley Creek (Atlanta area), Georgia	5.0	4.1	130	123	86	0.57	0.31	Biological nutrient removal with added ferric chloride followed by membrane bioreactor	Thickening, aerobic digestion and dewatering
Lone Tree (Arapahoe County) Colorado	2.4	1.6	Daily 50	40	30	0.64	0.53	Ferric chloride membrane bioreactor using Zenon membranes	Aerobic digestion and dewatering
Walton, New York	1.6	1.1	150		46		0.76	Activated sludge with coagulant addition followed by dual stage Dynasand filtration	Aerobic digestion and dewatering
Iowa Hill (Breckenridge), Colorado	1.5	0.8	Daily 50, annual 225 lbs	9	8	1.01	0.93	Activated sludge with bio-P, BAF, Densadeg with alum, Dynasand filtration	None
Pinery, Colorado	1.0	0.6	Month 50, daily 100, annual 150 lbs	29	31	0.40	0.41	5-stage Bardenpho, Trident process with alum (adsorption clarification, multimedia filtration)	Holding basins, dewatering and air drying
Stamford, New York	0.5	0.4	200		20		0.96	Activated sludge with coagulant addition followed by dual stage Dynasand filtration	Aerobic digestion and dewatering

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Table 2 summarizes the pilot testing results at the RPWRF and indicates that 20 μg/L is probably the best any filtration or membrane technology can achieve. Small full-scale facilities indicate that 30 to 40 μg/L are more likely the best effluent concentrations achievable with current filtration or membrane technologies for full-scale facilities. The best years for Rock Creek indicate that 50 to 60 μg/L may be achievable with conventional multimedia effluent filters. The effects of plant size and solids processing are significant unknowns that could affect the ability of plants of substantial size to achieve very low levels of total phosphorus. Nonideal conditions, partial failures of large numbers of parallel process units and human challenges of operating larger systems with large numbers of parallel process units could reduce the ability of larger WWTPs to reliably achieve extremely low concentrations of total phosphorus. Anaerobic digestion may release phosphorus changing chemical requirements or create chemical forms of phosphorus that are not removed by chemical reaction and affect phosphorus removal when attempting to achieve extremely low effluent concentrations.

TABLE 2
Summary of Fall 2005 RPWRF Phosphorus Removal Technology Pilot Testing

Technology	Final Effluent Log Normal Average Total Phosphorus (μg/L)	Coefficient of Variation of Final Effluent Total Phosphorus (μg/L)
US Filter MicroflocTrident	18	0.47
Parkson DynaSand D2 Filtration	16	0.35
Zenon Membrane Filtration	16	0.46

At this time, the lowest demonstrated effluent total phosphorus limit for plants of substantial size (>2.5 mgd) is 100 μg/L based on using a seasonal discharge limit. This limit has been achieved by Rock Creek, Durham, one of two years for Alexandria and one of two years at Cauly Creek. Rock Creek and Durham had effluent total phosphorus limits of 70 μg/L for several years prior to 2004 and 2005. Both plants were able to achieve 50 to 60 μg/L to comply with this effluent limit. However, both of these WWTPs had experience with high levels of phosphorus removal prior to the initiation of these limits and the processes were familiar to plant staff and process control analysts. Phosphorus removal and new wastewater treatment unit processes will be added to all the Spokane River WWTPs. There will be a need to train operations and maintenance staff, learn optimum control strategies and debugging new wastewater treatment unit processes to achieve optimum results. Overly restrictive effluent limits will be counter-productive because they will discourage experimentation to determine how well the new processes can perform for fear of violating NPDES permit limits. Seasonal averaging appears essential to successful compliance at low effluent phosphorus levels since actual plant performance shows a high degree of variability at all plants examined. It may seem counterintuitive, but short-term limits must be substantially higher than the seasonal limits because of the inherent variability of the effluent concentration and fewer results included in the averages for the shorter time periods.

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It is likely that concentrations of phosphorus less than 100 μg/L can be achieved at larger plants only by use of more chemicals, better process control, highly trained operators, and state-of-the-art phosphorus removal technology.

It is recommended that longer-term, larger-scale pilot plants be operated to assist in the selection of the phosphorus removal technology that achieves the lowest concentrations of final effluent phosphorus in a cost effective manner. Engineering studies should be conducted using the data from the recently completed pilot studies to evaluate phosphorus removal technologies. Factors including initial capital cost, space requirements and ability to fit on available site area, chemical requirements, operation and maintenance issues and final effluent phosphorus concentration should be evaluated to determine one or two technologies for additional pilot testing. It is recommended that the pilot test be approximately 1 mgd and continue for a period of 1 year. A final engineering evaluation should be conducted to determine the phosphorus removal technology to implement.

It is recommended that the new facilities be operated for a period of 5 years to establish the final NPDES permit limits for final effluent phosphorus. Issues such as operating large numbers of parallel treatment processes, optimum chemical dosages and operating strategies and the effect of anaerobic digestion can not be determined from pilot testing. This can only be determined from full-scale operation at the WWTPs. It is likely that there will be construction and startup issues that will affect the first year of operation and it is unlikely that optimum phosphorus removal will be achieved. The next 2 years would provide the opportunity to experiment with different strategies to optimize performance. The final 2 years would provide the opportunity to operate using agreed upon strategies to determine the lowest feasible final effluent phosphorous concentrations and this data would be used to establish final NPDES limits.

Analytical Considerations

RPWRF and an accredited private local laboratory in the Spokane area split samples for analysis of total phosphorus during the pilot testing of phosphorus removal technologies at the RPWRF. The results of the laboratory analyses are shown in Figure 1. The individual measurements are shown as points on the graph. The straight line represents perfect correlation between the measurements made by the two laboratories. The results varied widely, so much that there is no meaningful statistical correlation of the results. Typical variation was 2-6 μg/L and several samples varied by more than 25 μg/L. As a result, it is important to recognize the challenges of evaluating WWTPs operating at very low effluent concentrations of total phosphorus and complying with very low total phosphorus effluent permit limits.

Analytical quality control is essential to obtain reliable laboratory results at very low concentrations. The quality of the total phosphorus concentrations in the data used for this analysis is unknown and the uncertainty level in individual measurements is potentially similar in magnitude to the desired effluent total phosphorus concentration. It is more of a challenge for smaller WWTPs to achieve the necessary level of quality control with laboratory staff that may have less training and fewer resources to conduct the laboratory analysis. The RPWRF experience indicates that even two highly skilled laboratories can measure very different concentrations of phosphorus in the same sample.

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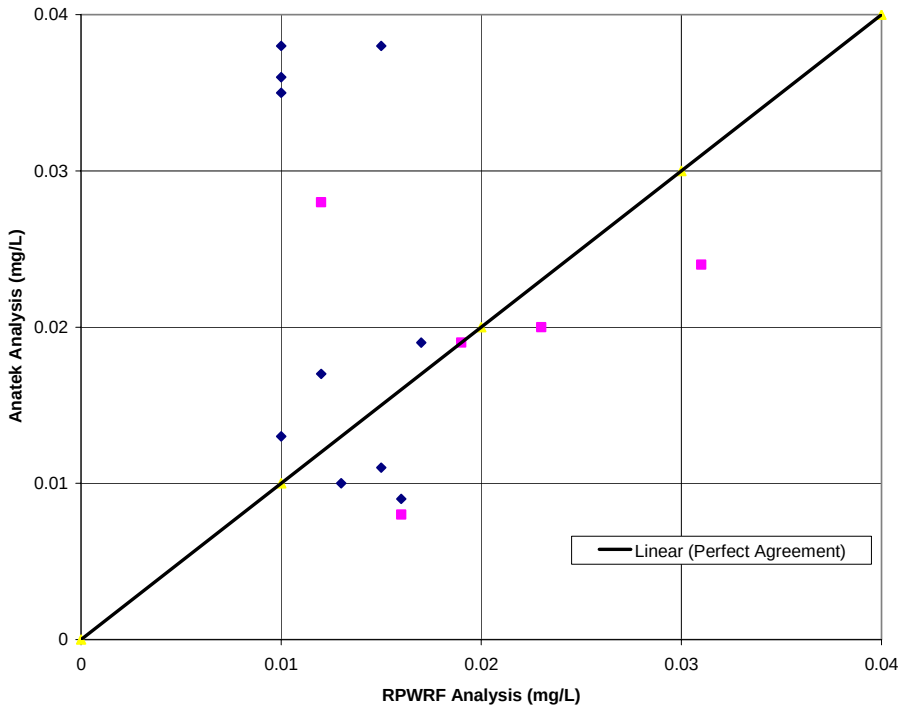
Figure 1. Analytical Phosphorus Measurement



RPWRF laboratory staff determined that the quantitation limit for total phosphorus was 5 µg/L. This is the lowest concentration that can be measured with the phosphorus analysis technique used by RPWRF and is comparable to the best several universities can measure. This creates some uncertainty about the data for the Iowa Hill (Breckenridge, Colorado) WWTP that has a substantial amount of data between 1 and 10 µg/L.

Las Vegas, Nevada

The City of Las Vegas operates a 91-mgd advanced treatment plant that combines an older plant with a relatively new (May 2003) biological nutrient removal facility (BNR). The process includes multiple parallel trains with trickling filters, activated sludge, effluent filters and the new BNR facilities. The older treatment plant consists of trickling filters, nitrification activated sludge, and effluent filtration. Chemical phosphorus removal was practiced at the older plant with chemical addition (ferric) prior to primary clarification. The new BNR facility started operation in May 2003 and treats 30 mgd of the total plant flow. The BNR effluent is combined with the old treatment system prior to effluent filtration.

The relatively new (May 2003) biological nutrient removal facility consists of four 7.5-mgd activated sludge process trains with three anaerobic zones, three anoxic zones, and a complete mixed aerobic zone. The aerobic zone is designed as a racetrack with mixers moving the liquid around the basin. Primary clarification is available with ferric feed as an option, mainly used for odor control at low doses.

The solids processing system consists of gravity thickening of primary sludge, centrifuge thickening of waste activated sludge, anaerobic digestion, dewatering and truck hauling of biosolids.

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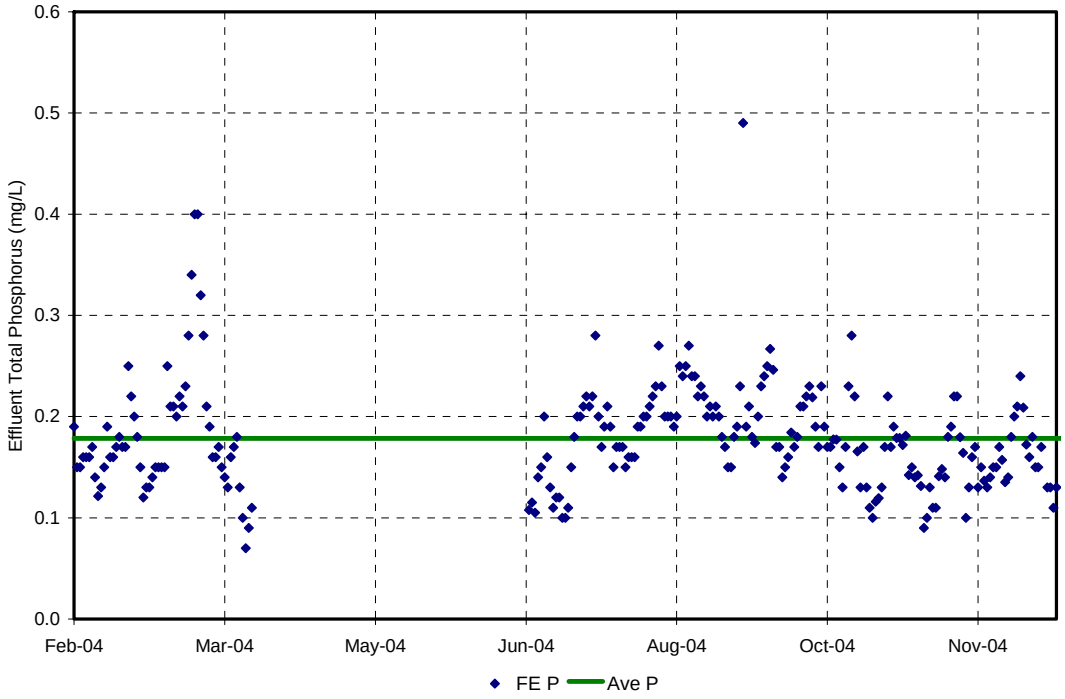
The City of Las Vegas plant discharges into the Las Vegas Wash, which ultimately flows into Lake Mead and the Colorado River. Seasonal phosphorus and ammonia limits apply to the plant. The mass load allocation to the Las Vegas Wash is shared with two other wastewater plants: Clark County and the City of Henderson. As flow increases, the effluent concentration limit decreases. Summer and winter effluent limits for phosphorus at 91 mgd are 0.17 mg/L (126 lbs/day). The summer (March through October) effluent ammonia nitrogen limits are 0.48 mg/L (366 lbs/day) and the winter (November to March) limits are 0.56 mg/L (427 lbs/day).

Daily Las Vegas plant effluent phosphorus data was reviewed from February 1 to December 23, 2004 and from January 1 to July 9, 2005. This data is shown graphically in Figures 2 and 3. The log normal mean of the daily effluent data for 2004 was 0.179 mg/L and for 2005 was 0.152 mg/L.

Figure 2. 2004 Las Vegas WWTP Effluent TP



Alexandria, Virginia

Alexandria, Virginia is a 54-mgd WWTP. Phosphorus removal is accomplished by ferric chloride addition prior to the primary clarifiers, ferric chloride addition following activated sludge ahead of the secondary clarifiers, alum addition prior to chemical clarifiers and multimedia filtration. Solids are processed by pasteurization, anaerobic digestion and dewatering. Daily total phosphorus in the final effluent data for 2003 and 2004 are shown in Figures 4 and 5 along with the log normal average for each year. Final effluent total phosphorus averaged 134 and 88 µg/L well within the permit limit of 180 µg/L for a monthly average. The effluent total phosphorus in 2004 is much lower than in 2003 and there is less daily variation.

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Figure 3. 2005 Las Vegas WWTP Effluent TP

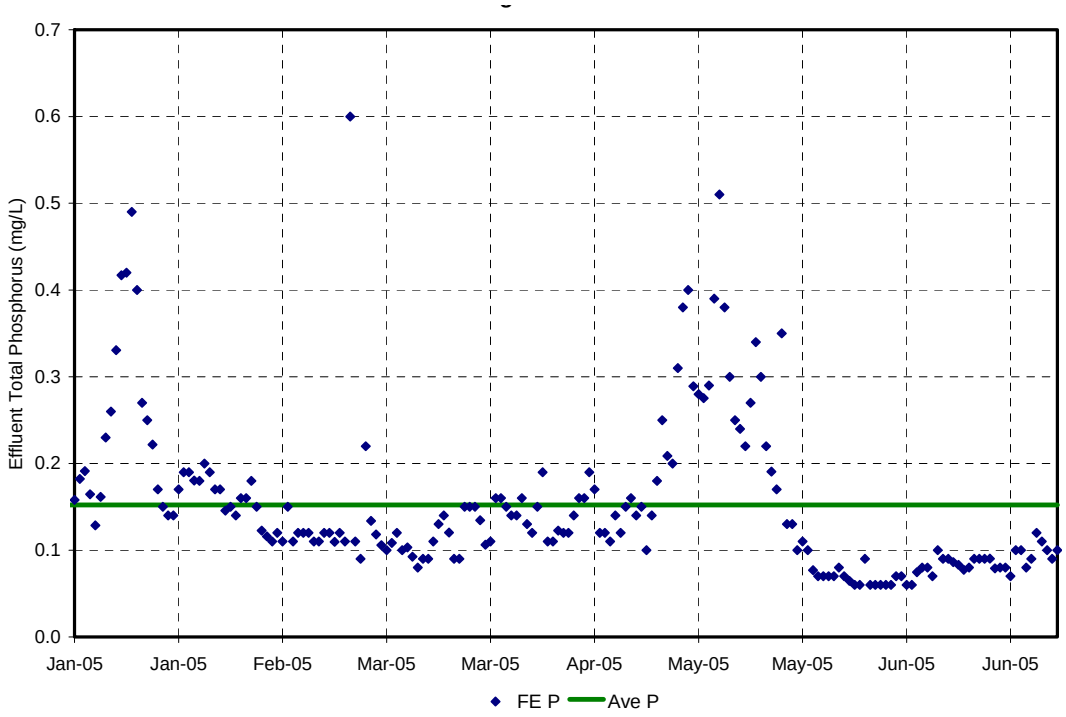

Figure 4. 2003 Alexandria, Virginia Effluent Phosphorus

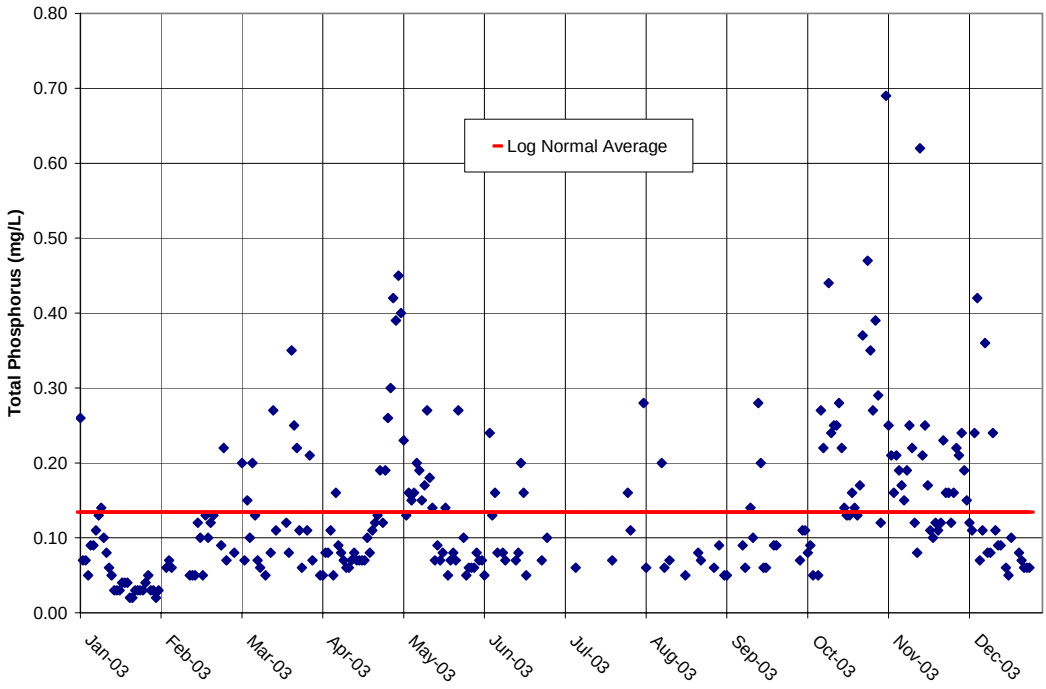

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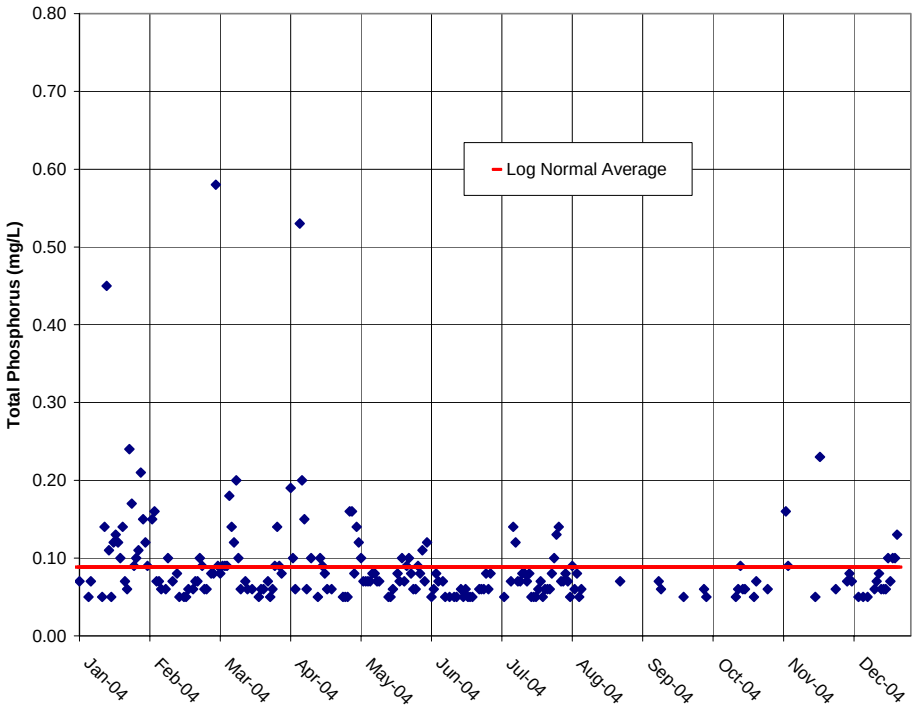
Figure 5. 2004 Alexandria, Virginia Effluent Phosphorus



Rock Creek, Oregon

Rock Creek WWTP has a capacity of 34 mgd. It is operated by Clean Water Services and serves the Hillsboro area west of Portland. Phosphorus is removed by alum addition to the primary clarifiers, alum addition followed by chemical clarification and alum addition followed by multimedia filtration. Solids are processed by anaerobic digestion and dewatering. Daily total phosphorus in the final effluent for years 2004 and 2005 is shown in Figures 6 and 7 with the log normal average for the phosphorus removal season which runs from May to November. Effluent total phosphorus is higher in 2004 than 2005, but was fairly consistent. Effluent total phosphorus was less than the seasonal average of 100 µg/L.

Average effluent total phosphorus is higher in 2004 and 2005 compared to 2001 through 2003 when log average effluent total phosphorus was 48 to 57 µg/L. The NPDES limits for phosphorus were relaxed from 70 µg/L to 100 µg/L and apparently the WWTP is able to reduce chemicals and reduce the phosphorus removal efficiency. The daily data show periods where total effluent phosphorus is 25 to 50 µg/L, but there are other periods when total effluent phosphorus is much higher. With this data, it is not possible to conclude what the minimum effluent concentration of total phosphorus would be if the NPDES permit limits for total phosphorus were lower.

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Figure 6. 2004 Rock Creek, Oregon Effluent Phosphorus

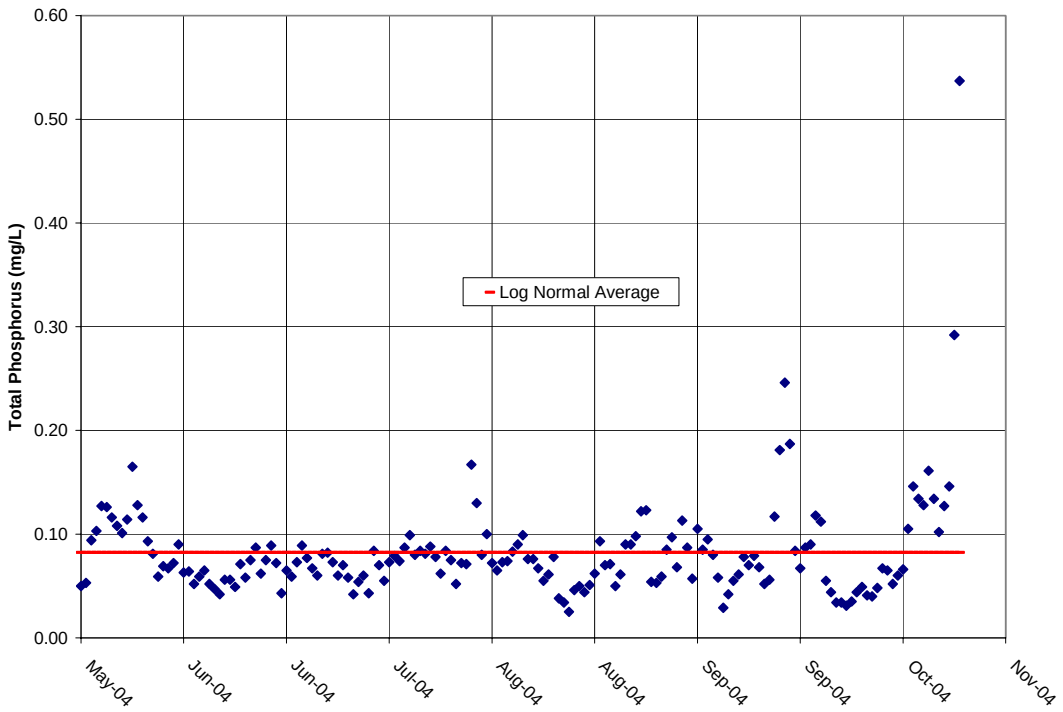
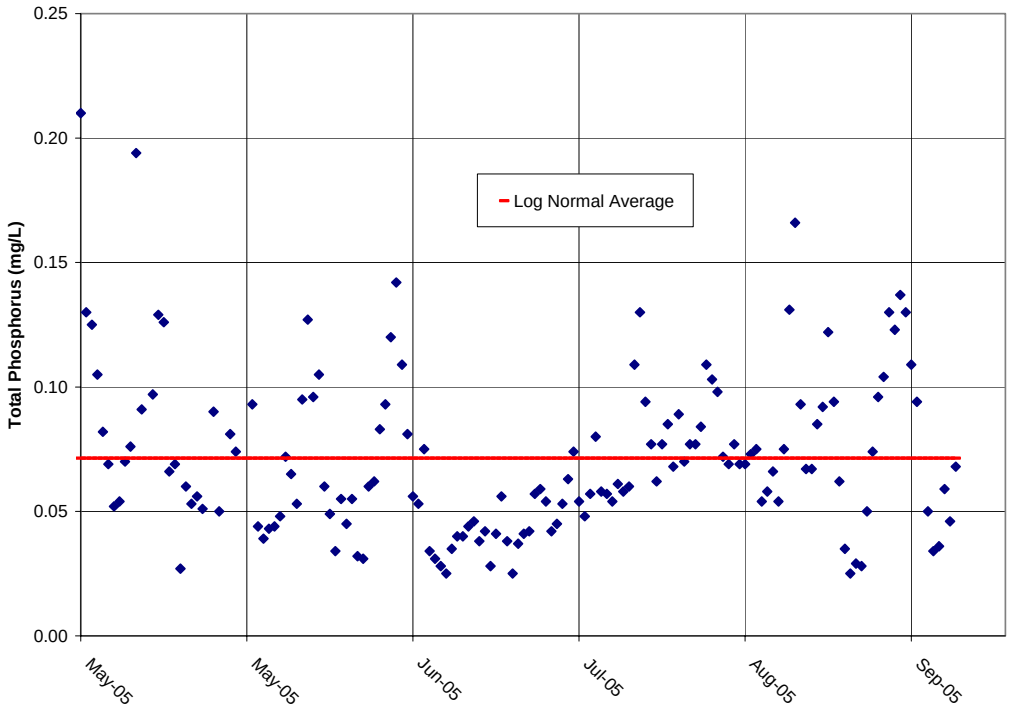


Figure 7. 2005 Rock Creek, Oregon Effluent Phosphorus



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Durham, Oregon

The Durham facility located in Tigard, Oregon is operated by Clean Water Services of Washington County (District). The plant was designed to operate as a biological phosphorus removal plant in either UCT or A^2O mode and typically operated in A^2O. Alum can be added upstream of the primary, secondary, and tertiary treatment processes to meet the seasonal total phosphorus limit.

The biological nutrient removal process follows screening, grit removal, and primary clarification. Lime is added for alkalinity control. Denitrification is practiced to recover alkalinity and oxygen but there is no total nitrogen control requirement in the effluent discharge permit. The tertiary process consists of chemical clarifiers using alum and polymer, followed by sand media filters. Sodium hypochlorite is used for disinfection and sodium bisulfate is used for dechlorination.

Primary sludge is fermented in a two-stage fermenter/thickener, and volatile fatty acids (VFAs) are elutriated and returned to the secondary treatment process. Waste-activated sludge and chemical sludge are thickened using centrifuges. Primary, waste activated and chemical sludges are anaerobically digested and centrifuge dewatered prior to land application. Dewatering centrate is returned to the primary effluent pump station upstream of the aeration basins. Ferric can be added to the anaerobic digester feed for odor and struvite control.

The Durham plant discharges to the Tualitin River and operates under a watershed NPDES discharge permit that includes multiple treatment plants. Discharge permit limits are seasonal and the plant is required to remove phosphorus and ammonia nitrogen (nitrification) between the months of April and November. During the summer months, the plant must an effluent phosphorus concentration of 0.110 mg/L and an effluent ammonia nitrogen concentration of 1 mg/L on a monthly median basis.

Daily Durham plant effluent phosphorus data was reviewed from May 10 to October 20, 2004 and from May 9 to July 29, 2005. The data is shown graphically in Figures 8 and 9. The log normal mean of the daily effluent data for 2004 was 0.102 mg/L and for 2005 was 0.073 mg/L.

The solids process consists of waste solids thickening with a membrane sludge thickener, followed by aerobic digestion, and centrifuge dewatering of digested sludge.

Cauley Creek, Georgia

The Cauley Creek Wastewater Reclamation Facility is located in North Fulton County, Georgia and consists of nitrification, denitrification, and both biological and chemical phosphorus removal. The treatment process consists of preliminary treatment with screening and grit removal, followed by secondary treatment with pre-anoxic, anaerobic and aerobic sequences for nitrogen and phosphorus removal and membrane biological reactor (MBR) for liquid and solids separation, and UV disinfection. A ferric dose of 15 to 20 mg/L is added before the flow reaches the MBR tank for chemical enhanced phosphorus to meet the effluent total phosphorus limit.

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Figure 8. 2004 Durham AWWTP Effluent TP

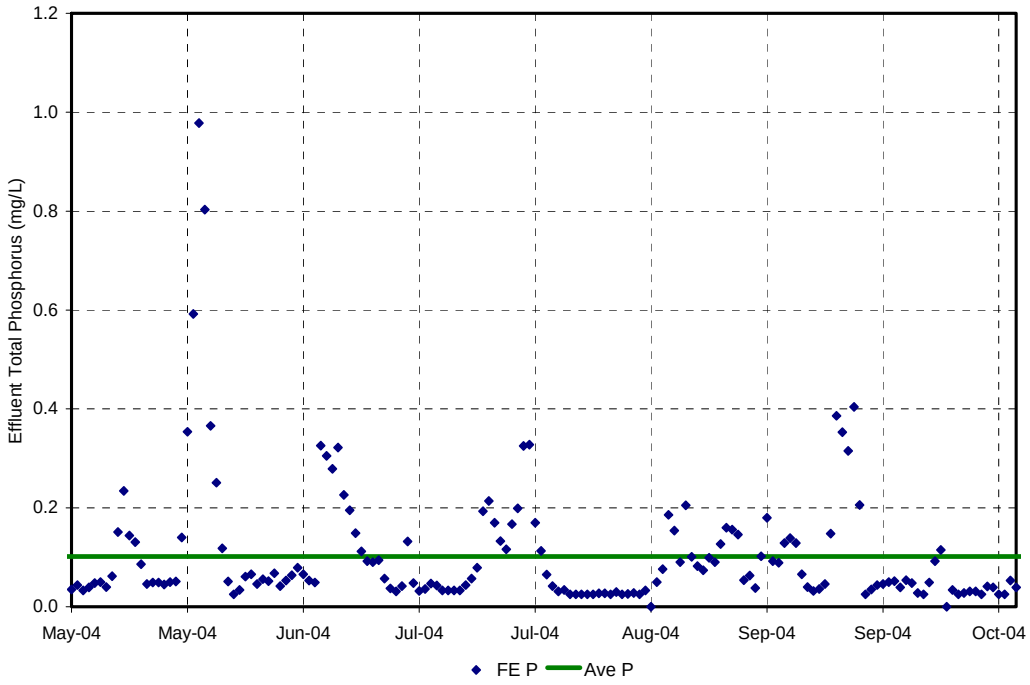
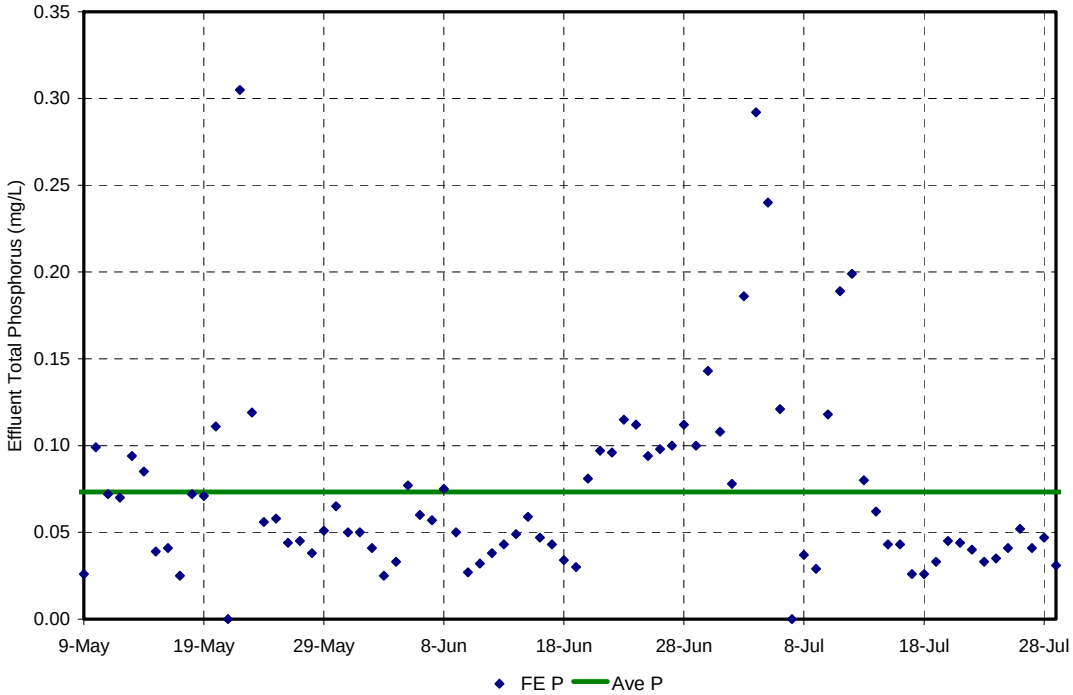


Figure 9. 2005 Durham AWWTP Effluent TP



Fulton County sells much of the reclaimed wastewater from the Cauley Creek plant for reuse to local customers, such as golf courses. Unsold treated wastewater is either used to irrigate on-site hayfields or stored on-site in effluent holding ponds. During the cold weather season, the facility can discharged treated effluent to Cauley Creek, a tributary to the Chatahoochee River. Effluent discharge requirements for total phosphorus are

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<0.13 g/L. There are also effluent requirements for turbidity (<0.5 NTU), BOD (<2.9 mg/L), TSS (<5 g/L), total nitrogen (<10 mg/L), and ammonia nitrogen (<0.5 mg/L).

Daily Cauley Creek plant effluent phosphorus data was reviewed from September 10 to December 31, 2004 and from January 20 to January 31, 2005. This data is shown in Figures 10 and 11. The log normal mean of the daily effluent data for 2004 was 0.123 mg/L and for 2005 was 0.086 mg/L.

Figure 10. 2004 Cauley Creek Effluent TP

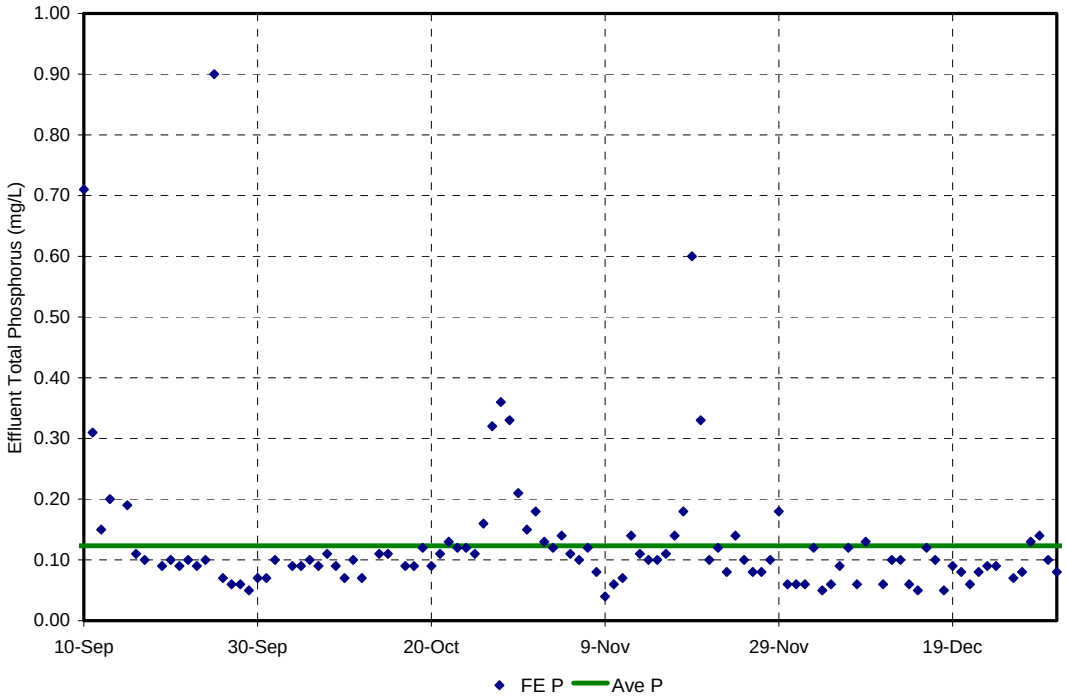
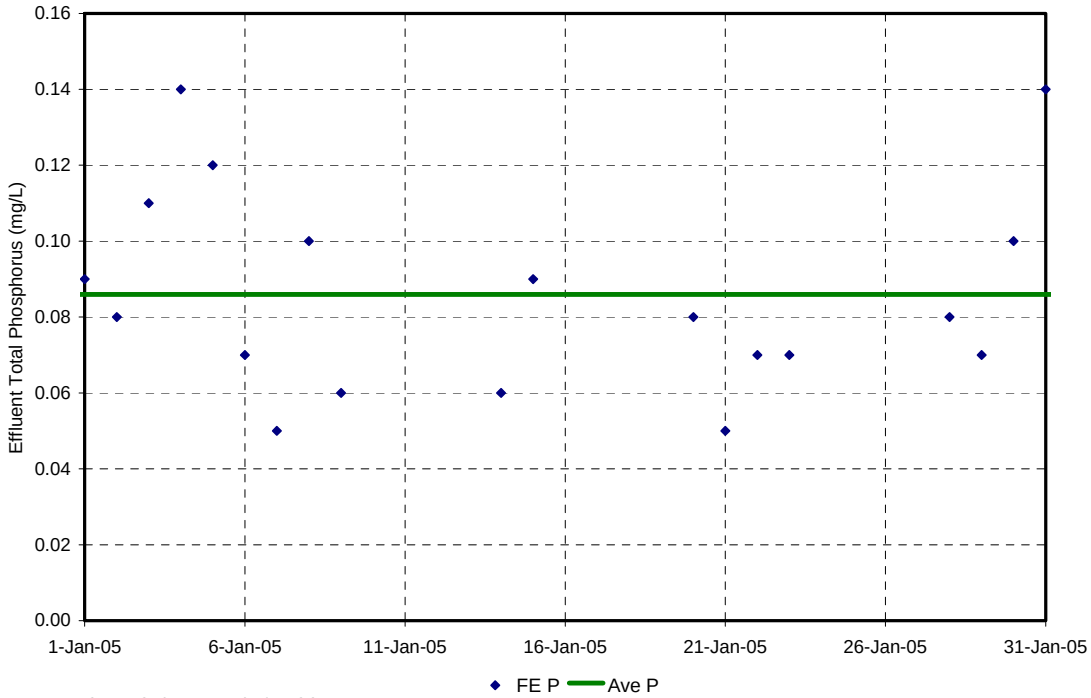


Figure 11. 2005 Cauley Creek Effluent TP



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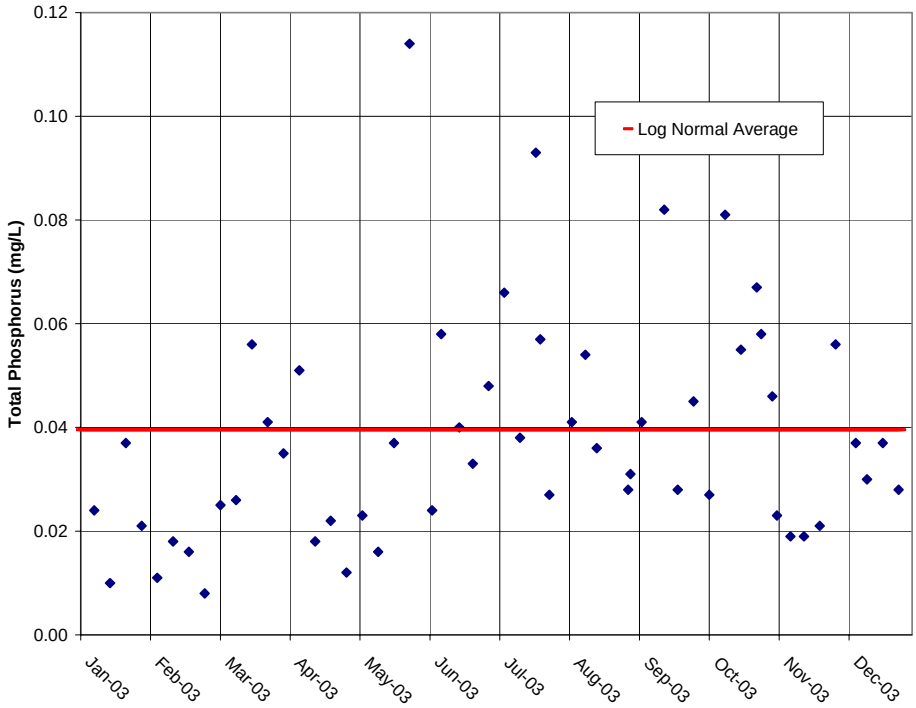
Lone Tree, Colorado

Lone Tree WWTP has a capacity of 2.4 mgd. It serves Arapahoe County Colorado in the Denver area. Zenon membranes in a bioreactor activated sludge process using ferric chloride to precipitate phosphorus are used for phosphorus removal. Solids are processed using aerobic digestion and dewatering. Effluent total phosphorus in 2003 and 2004 are shown in Figures 12 and 13. Effluent total daily phosphorus limit is reportedly 50 µg/L. Total effluent phosphorus log normal average concentration was 40 µg/L in 2003 and 30 µg/L in 2004. Daily results frequently exceed 50 µg/L. Lone Tree is a small WWTP and the effluent sampling frequency is once per week. There are periods of time where final effluent total phosphorus is 20 µg/L or less, but there are other times when the total phosphorus is much higher.

Figure 12. 2003 Lone Tree (Arapahoe County), Colorado Effluent Phosphorus



Walton, New York

The Village of Walton facility is an activated sludge treatment plant with dual sand filtration of the secondary effluent. The dual sand process uses two Parkson DynaSand™ continuous backwash upflow filters in series. The first filter is approximately 2 meters in depth and uses coarse sand media. The second filter is approximately 1 meter in depth and uses fine sand media. A coagulant is added before the first stage filter to precipitate soluble phosphorus and a lamella settler is used to capture solids between stages and improve process throughput. A variety of coagulants have been used in this process including PASS®

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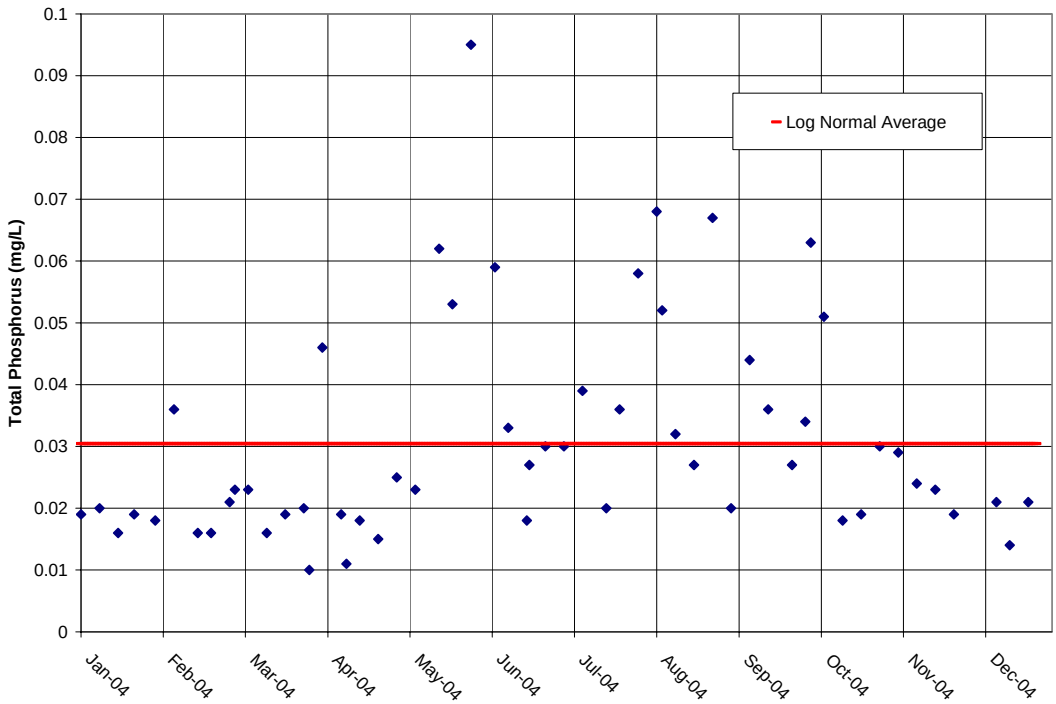
Figure 13. 2004 Pine Tree (Arapahoe County), Colorado Effluent Phosphorus



(Poly-aluminum-silicate-sulfate), manufactured by Handy Chemical (now Eaglebrook, Inc.). The plant has an influent equalization basin and chlorine disinfection of the effluent.

Waste solids are aerobically digested, dewatered in a belt filter press, and landfilled.

The Walton plant discharges to the New York City watershed where effluent phosphorus limits are between 1.0 mg/L and 0.2 mg/L depending upon plant flow. The Walton permit was recently revised to lower the monthly average phosphorus limit to 0.15 mg/L, based on a 24-hour composite sample taken once a week, in order to increase permitted flows to 1.55 mgd. There is also a mass loading limit for phosphorus of 1.95 lbs/day which was based on the historically permitted flow rate of 1.17 mgd and an effluent limit of 0.2 mg/L.

Walton plant effluent phosphorus data taken weekly from January 9 to August 28, 2005 was reviewed and are shown in Figure 14. The log normal mean of the weekly effluent data for 2005 was 0.046 mg/L. The effluent data ranged from 0.01 to 0.49 mg/L in 2005.

Iowa Hill, Colorado

The Iowa Hill WWTP has a design capacity of 1.5 mgd. It serves the Breckenridge area. Phosphorus removal is accomplished in three steps. First, phosphorus is removed biologically using activated sludge with an anaerobic zone. Then phosphorus is removed using alum with chemical clarification in proprietary process known as the Densadeg process. Settled solids are recirculated in the Densadeg process. The final step is filtration using Parkson Dynasand effluent filters. Solids are not processed at the WWTP as they are sent to another WWTP for processing.

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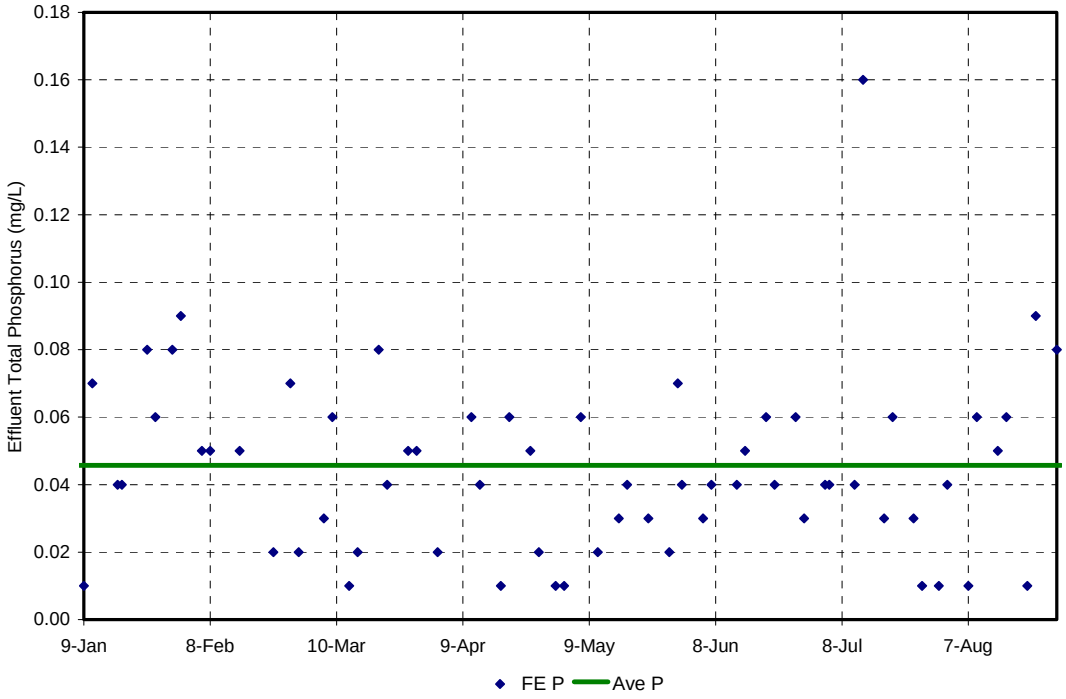
Figure 14. 2005 Walton WWTP Effluent TP



Figures 15 and 16 show daily and log normal average final effluent total phosphorus in 2003 and 2004. The average in both years is reported to be less than 10 µg/L. As discussed earlier, the large number of laboratory observations less than 10 µg/L is in apparent conflict with RPWRF laboratory experience and Iowa Hill laboratory procedures should be reviewed in detail before the results are accepted as fact.

Pinery, Colorado

The Pinery WWTP has a capacity of 1.0 mgd. It removes phosphorus initially using a five-stage biological activated sludge process called the Bardenpho process. The phosphorus is removed using alum in U.S. Filter's Trident process consisting of adsorption clarification followed by multimedia filtration.

Figures 17 and 18 show daily and log normal average final effluent total phosphorus in 2003 and 2004. The average for both years is approximately 30 µg/L. They are easily meeting their NPDES effluent total phosphorus of 50 µg/L for a monthly average and 100 µg/L for a maximum day. The coefficient of variation is low for both years indicating very stable and consistent operation with small variation.

Stamford, New York

The Village of Stamford facility is an activated sludge treatment plant with dual sand filtration of the secondary effluent. The dual sand process uses two Parkson DynaSand™ continuous backwash upflow filters in series. The first filter is approximately two meters in depth and uses coarse sand media. The second filter is approximately one meter in depth

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Figure 15. 2003 Iowa Hill (Breckenridge), Colorado Effluent Phosphorus

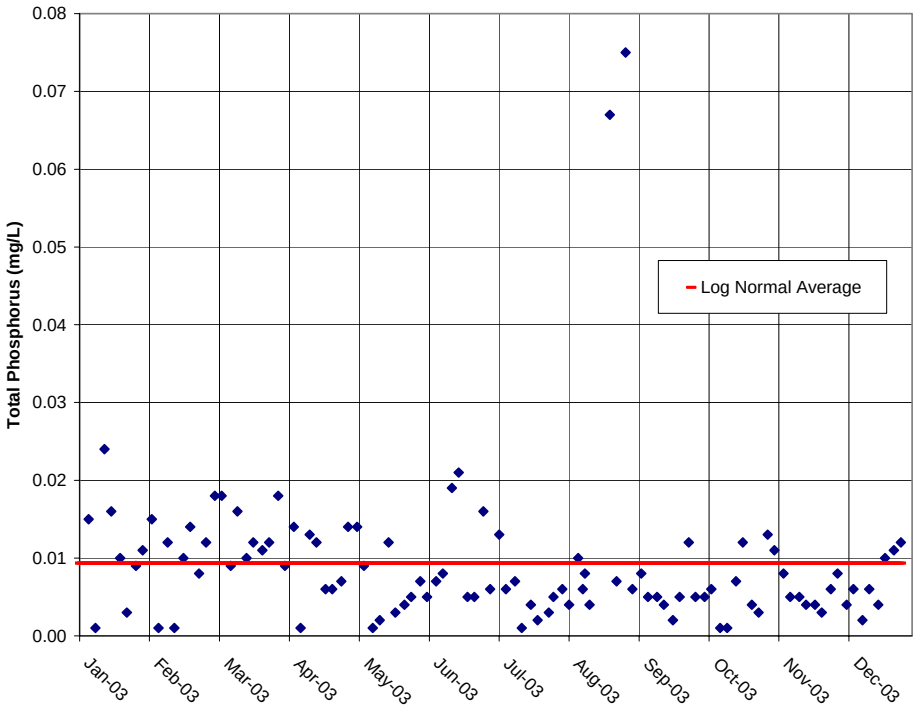

Figure 16. 2004 Iowa Hill (Breckenridge), Colorado Effluent Phosphorus

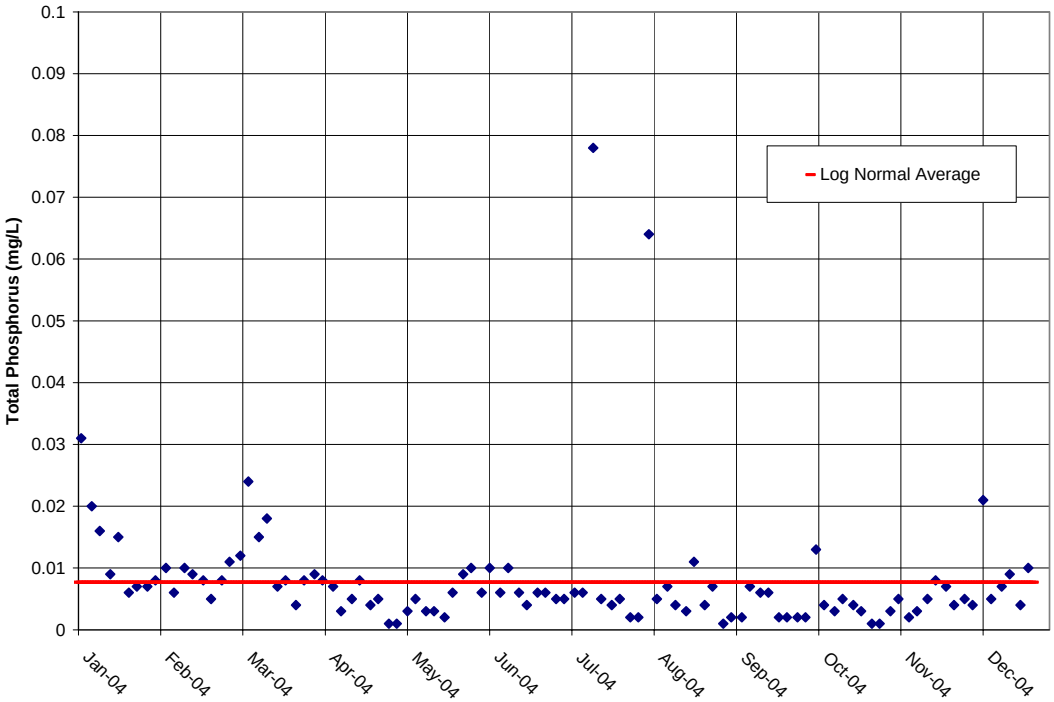

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Figure 17. 2003 Pinery, Colorado Effluent Phosphorus

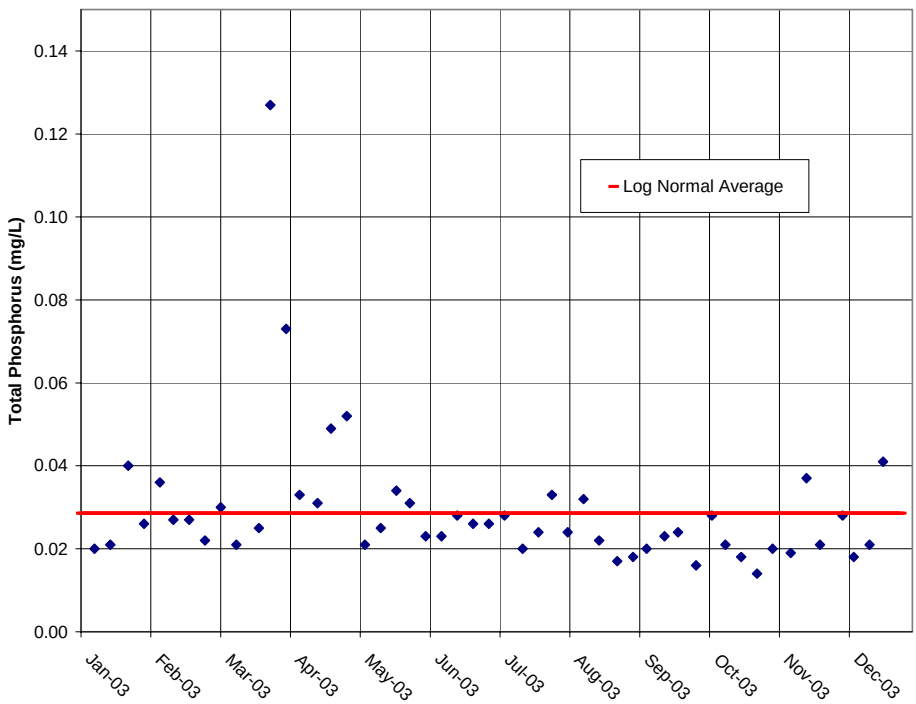
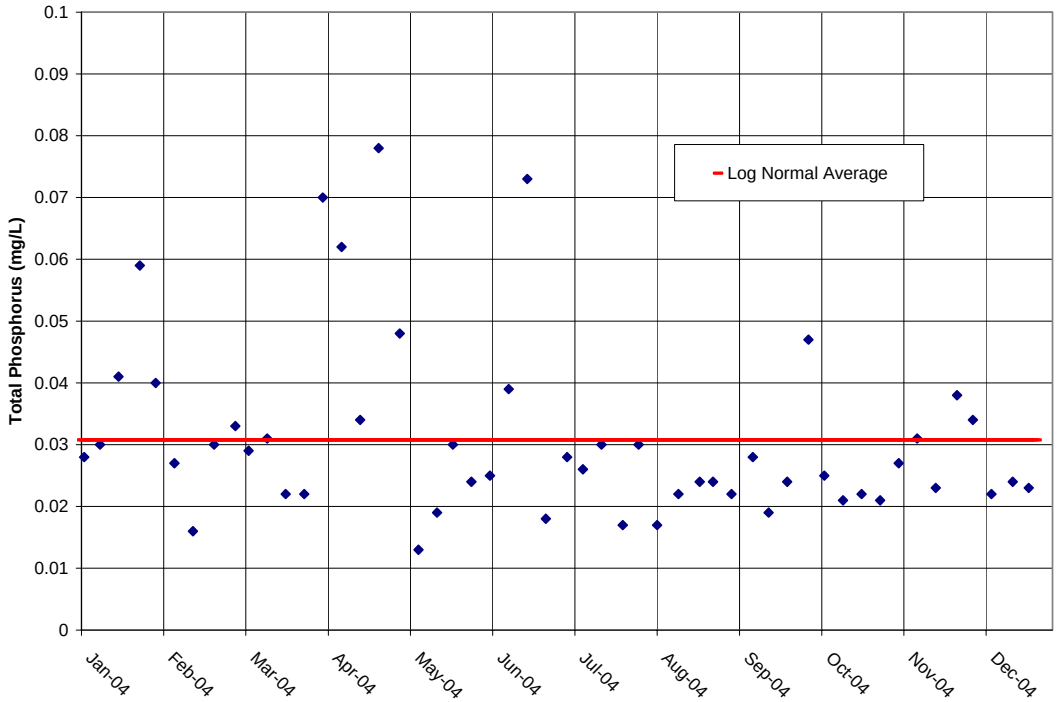


Figure 18. 2004 Pinery, Colorado Effluent Phosphorus



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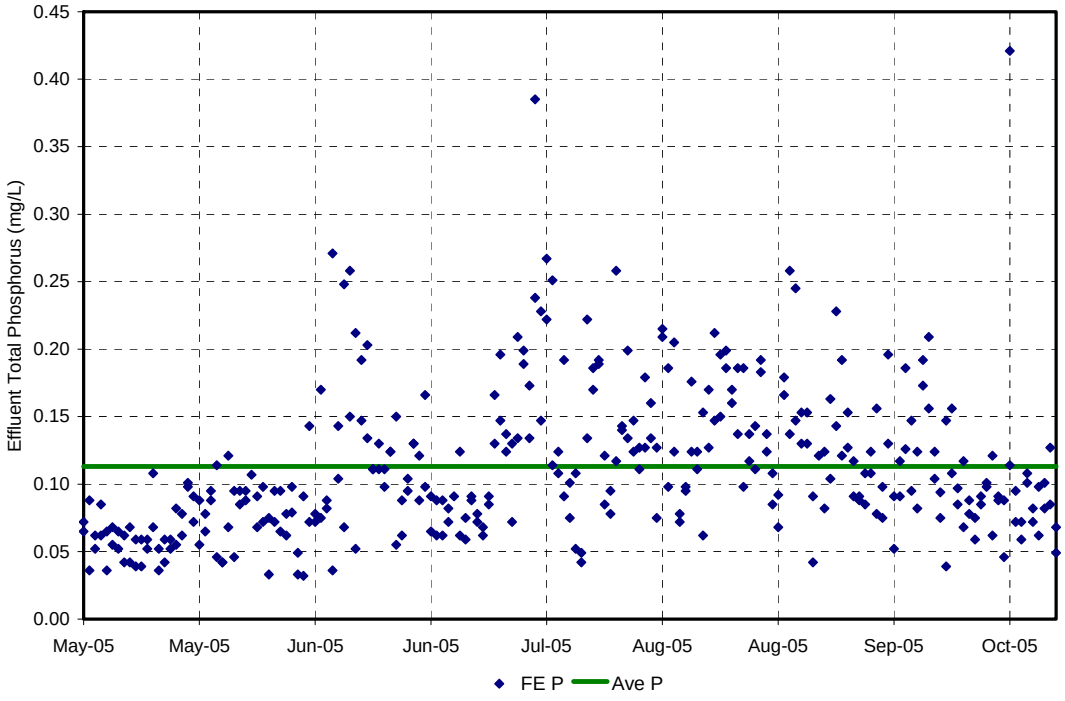
and uses fine sand media. A coagulant is added before the first stage filter to precipitate soluble phosphorus and a lamella settler is used to capture solids between stages and improve process throughput. A variety of coagulants have been used in this process including PASS® (Poly-aluminum-silicate-sulfate), manufactured by Handy Chemical (now Eaglebrook, Inc.). The plant has chlorine disinfection of the effluent.

Waste solids are aerobically digested, dewatered in a belt filter press, and landfilled.

The Village of Stamford plant discharges to the New York City watershed where effluent phosphorus limits are between 1.0 mg/L and 0.2 mg/L depending upon plant flow. The Stamford permit has a monthly average phosphorus limit to 0.20 mg/L, based on a 6-hour composite sample taken twice a month.

Stamford plant effluent ortho phosphorus data from field test kit analysis of morning and afternoon grab samples taken from May 1 to October 16, 2005 (335 data points) was reviewed and is shown in Figure 19. The log normal mean of the grab sample effluent data for 2005 was 0.113 mg/L. The effluent data ranged from 0.03 to 0.42 mg/L in 2005.

Figure 19. 2005 Stamford WWTP Effluent Ortho-P (AM and PM Grab Samples and Field Tests)



From January through August 2005, the average effluent phosphorus reported by the Stamford plant was 0.015 mg/L based on certified laboratory analysis of the twice monthly 6-hour composite samples. Examination of 10 Stamford data points from May through September from certified laboratory testing of 6 hour composite samples taken twice show a range from 0.006 to 0.039 mg/L. This is shown in Figure 20. The log normal mean of the twice monthly samples from the summer of 2005 was 0.02 mg/L. These values for total

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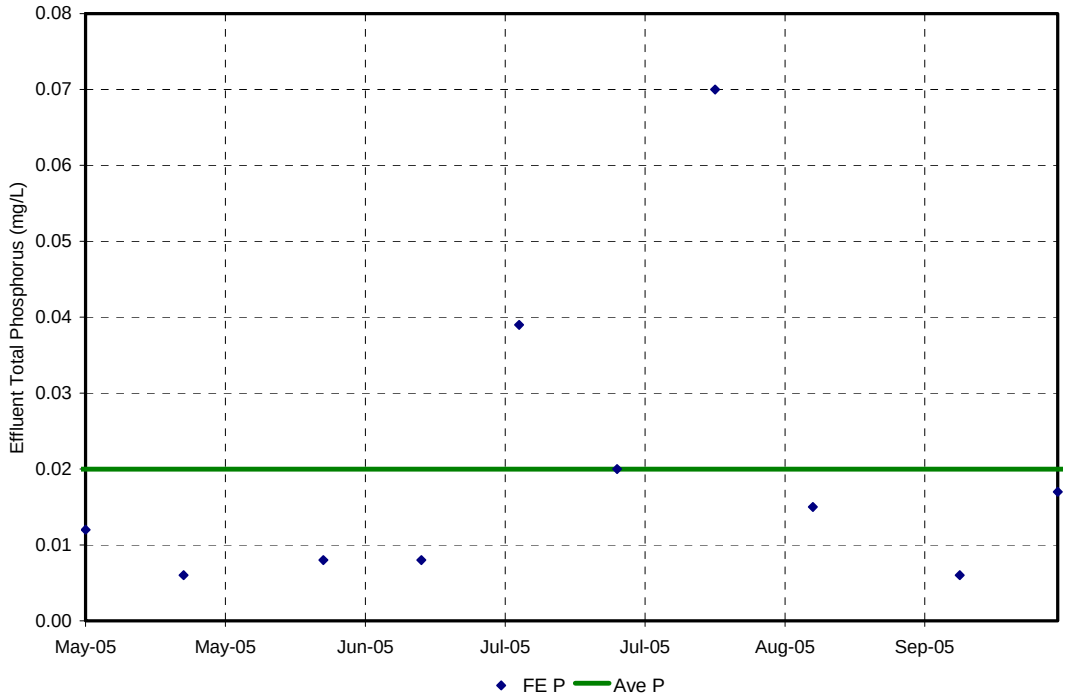
phosphorus are significantly lower than the orthophosphate values from the field test kit grab samples.

Figure 20. Stamford WWTP Effluent TP (Lab Samples)



Fall 2005 RPWRF Phosphorus Removal Technology Pilot Testing

Pilot testing of phosphorus removal technologies was conducted in September and October of 2005 at the RPWRF operated by the City of Spokane. Parkson Dynasand D2 filtration, US Filter Microfloc Trident and Zenon membrane filtration each operated pilot facilities for approximately 1 month each. These technologies were previously identified as having the potential to achieve the lowest total phosphorus in the final effluent. Final effluent phosphorus was analyzed by the RPWRF laboratory and some samples were split with Anatek, a privately owned laboratory in the Spokane area.

Parkson Dynasand D2 filtration consists of alum precipitation of phosphorus followed by filtration by two Parkson continuous backwash sand filters operated in series. The first stage filter uses larger sand grain size than the second stage filter. It has been applied in New York state and reportedly can reduce total phosphorus to as low as 10 µg/L. Figure 21 summarizes the pilot test results of the Parkson Dynasand D2 filtration technology. The log normal average of all the data is 16 µg/L. Some of the individual data were as low as 10 µg/L and a couple were greater than 30 µg/L. Pilot testing was conducted from September 1 to October 10, 2005 and 24 samples were analyzed.

US Filter Microfloc Trident consists of alum or ferric chloride precipitation of phosphorus followed by an adsorption clarifier. The adsorption clarifier uses plastic beads in an upflow

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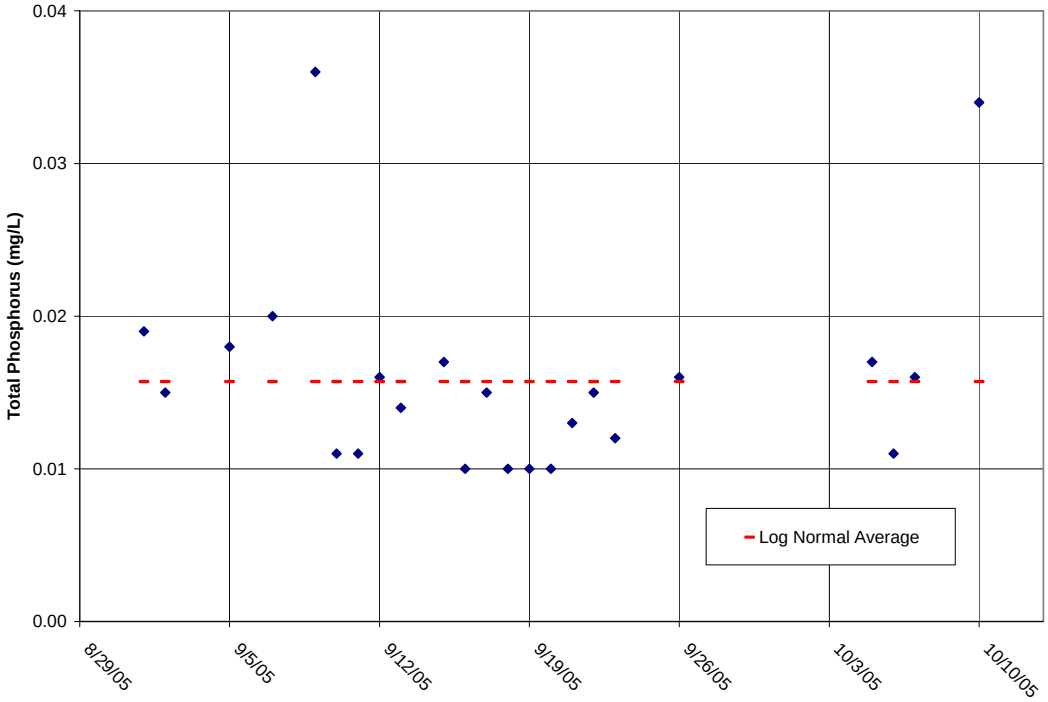
clarifier to flocculate and remove solids. The plastic beads reduce the size of the clarifier. The clarifier is followed by a multimedia conventional filter. Figure 22 summarizes the pilot results for the Trident technology. The log normal average of all the data is 18 µg/L.

Figure 21. Parkson DynaSand D2 Filtration Pilot Effluent Phosphorus



Individual data were as low as 9 µg/L and one was nearly 50 µg/L. Pilot testing results are for the period August 18 to October 7, 2005 and 20 samples were analyzed. Additional pilot testing was conducted late in October 2005, but the results were not available at the time this memorandum was prepared.

Zenon membrane filtration consists of alum precipitation of phosphorus, flocculation and filtration through immersed ultrafiltration membranes. The pores size of the membranes is smaller than suspended solids, pathogenic parasites and ova, bacteria and some virus. Figure 23 summarizes the pilot results for the Zenon technology. The log normal average for all the data is 16 µg/L. Individual data were as low as 8 µg/L and one was greater than 30 µg/L. Pilot testing was conducted from September 26 to October 19, 2005 and 17 samples were analyzed. The pilot testing was ongoing at the time this memorandum was prepared and additional data gathered after October 19 are not included in this evaluation.

Application of Pilot Testing Results to Predict Performance of Full Scale WWTPs

The pilot testing conducted in the fall of 2005 demonstrates the lowest concentrations achievable by state-of-the-art coagulation with metal salts and filtration with sand filters in series, multimedia filters or ultrafiltration membranes. The minimum average total

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Figure 22. US Filter MIcrofloc Trident Pilot Effluent Phosphorus

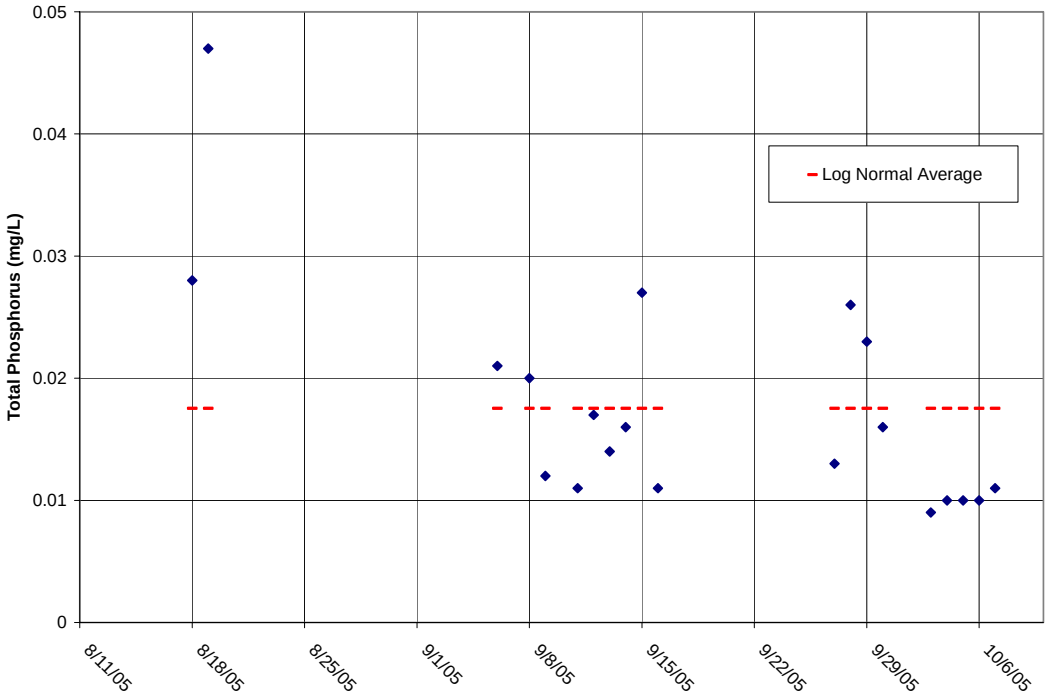
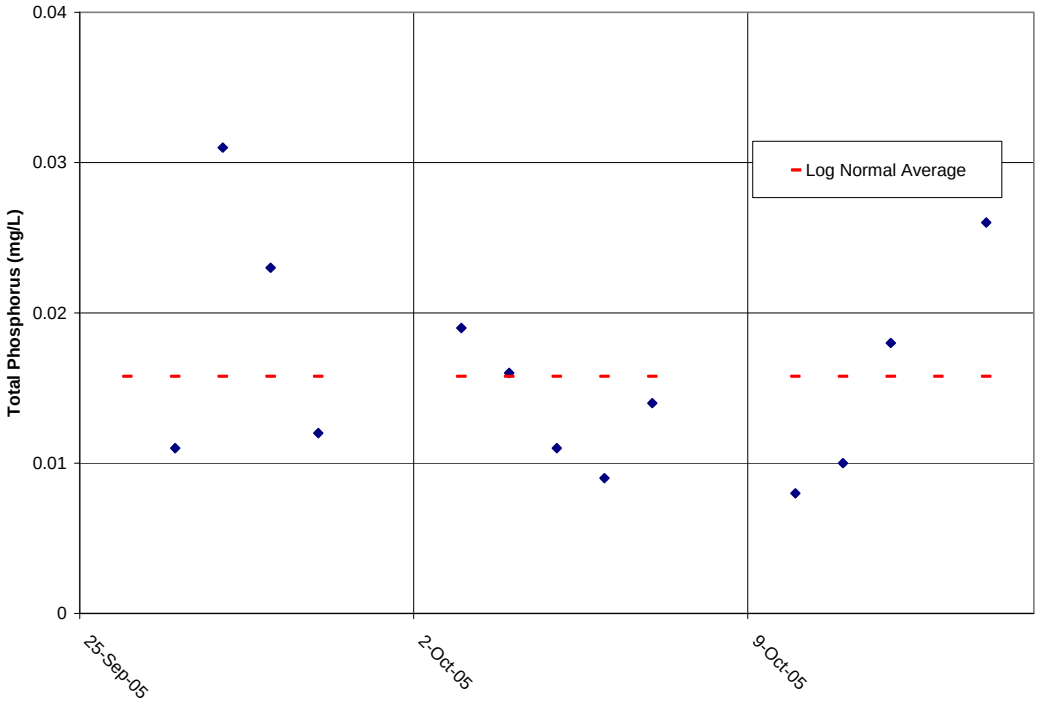


Figure 23. Zenon Membrane Filtration Pilot Effluent Phosphorus



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phosphorus concentration appears to be approximately 20 μg/L. All technologies could achieve total phosphorus concentrations of 10 μg/L on occasion, but all had samples much greater than 20 μg/L. These results were achieved over a short period of time using a very small pilot system operated by a highly trained technician with a very high incentive to be successful and no constraints were imposed on the quantity of coagulant chemicals used.

A full-scale facility must achieve results 200+ days per year with greatly varying influent conditions that may challenge standard operating strategies on occasion. Often the cause of poor results will be unknown and the changes to achieve success will also be unknown resulting in periods of operation by trial and error. This will lead to periods of poorer performance that can be observed in the full-scale facility data presented earlier and probably contributes to the variation in performance observed in the pilot testing. This is one reason why the full-scale facility will likely not be able to match the performance of the pilot facilities for at least periods of time.

A full-scale facility will have much larger individual process units and have many parallel trains of these process units. The pilot facility consisted of a single small process unit. A small unit is more likely to have "ideal" characteristics than a larger unit. The larger unit may not perform as well as the smaller unit because of the differences from "ideal" characteristics. In addition, many of these larger units must be operated in parallel. Additional process units increase the potential of a failure or partial failure of an individual unit that can reduce treatment performance. The requirement for multiple parallel process units and the need to respond to major changes in flow due to rainfall or snowmelt adds the potential for human error that can reduce treatment performance. These are additional reasons why a full-scale facility will likely not match the performance of the pilot facilities.

A full-scale facility requires a large number of trained operation and maintenance personnel of varying ability and motivation. A large facility requires 365 day per year, 24-hour-per-day operation and maintenance. There are five different crews needed to perform the operation and a large maintenance crew. The phosphorus removal process is an essential process, but only a part of the overall wastewater treatment plant facility. The level of attention provided by the pilot plant operating technician can not be duplicated by a full-scale facility because the labor costs would be exorbitant. With a large team of people there is inherently variation in skill levels and motivation compared to the pilot plant operating technician who is specifically trained to make the pilot unit perform and has no other duties. This will also contribute to the lower performance of the full-scale facility compared to the pilot facilities.

Last, the full-scale facility will have to treat the entire flow and deal with the recycle streams and impacts from anaerobic digestion that the pilot facility did not need to because it operated only a short time on a small fraction of the total flow. It is impossible to quantify the impact of these effects, but given the very low final effluent total phosphorus concentrations that are desired, small and subtle changes could be significant.

The only way to determine what minimum effluent concentrations of total phosphorus are reliably achievable is to operate the full-scale facilities for a period of time to gather operating data. Pilot testing is valuable for providing data to quantify what is possible with a given technology and to help evaluate competing technologies. The uncertainties associated with scaling up from pilot testing to full-scale operation are greater than the

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desired final effluent total phosphorus concentration. Therefore, it is recommended that final total phosphorus limits be established after 5 years of full-scale operation using the final 2 years of operation to establish the limits. The first 3 years will be needed to work through the construction and startup issues and to optimize the process so that the next 2 years reflect the best operation possible.

WWTP evaluation by CH2MHill 11-21-05.DOC

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