UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue, Suite 900
Seattle, Washington 98101-3140

Reply To: OWW – 130 March 24, 2009

Memorandum

To: David Moore
State of Washington, Department of Ecology
Water Quality Program

From: Brian Nickel
Environmental Engineer
US EPA Region 10, NPDES Permits Unit

Subject: Summary of previous reports and discharge monitoring report data for wastewater treatment plants achieving low effluent phosphorus concentrations

Introduction

Purpose

As a member of the engineering group for the Spokane River TMDL technical team, I was tasked to provide a summary of previous reports and effluent data regarding existing wastewater treatment plants achieving low (≤ 50 g/L) effluent phosphorus concentrations. This information is intended to be used to estimate the level of phosphorus removal that is currently being attained by processes in use at existing facilities, as a maximum monthly average concentration. I chose this measure of performance because, in general, effluent limitations for continuous discharges, whether from POTWs or other types of sources, must be expressed in terms of average monthly discharge limitations (40 CFR 122.45(d)).[1] This information could be used as a factor in the development of wasteload allocations and/or a water quality trading program for point sources in the revised draft total maximum daily load (TMDL) for the Spokane River and Lake Spokane, where phosphorus loading, from all sources, must be reduced significantly from current levels in order to ensure compliance with water quality standards.

Scope

This memorandum does not calculate a technology-based effluent limit for phosphorus. Rather, it is intended to inform (but not substitute for) a water quality-based analysis. Thus, this memorandum does not address the cost of attaining low effluent phosphorus concentrations, nor does it discuss the advantages, disadvantages, or design and operational considerations for the various treatment options that exist for achieving low

[1] The term "average monthly discharge limitation" is defined in 40 CFR 122.2. For practical purposes, for a concentration limit, it means it is the highest allowable arithmetic average concentration measured over the course of a calendar month. The abbreviated terms "average monthly limit" or "AML" are equivalent.

effluent phosphorus concentrations.[2] This memorandum is intended to address phosphorus removal in wastewater that is treated and discharged to surface water; wastewater re-use and land application are not addressed.

The final determination of wasteload allocations in a TMDL must ensure compliance with water quality standards, federal TMDL regulations (40 CFR Part 130), and any more stringent requirements of State law. This memorandum *does not* address the question of whether the levels of performance discussed herein are adequate to ensure compliance with these requirements.

This memorandum only discusses WWTPs that are, in my judgment, capable of consistently achieving an average monthly concentration of about 50 g/L or less. I chose this threshold for several reasons. First, as discussed below, previous efforts to evaluate performance in support of the Spokane River and Lake Spokane dissolved oxygen TMDL have identified 50 g/L as an effluent concentration that is "possibly attainable by municipal wastewater treatment plants on an average monthly basis."[3] Second, as discussed below, there are several operational full-scale WWTPs that can consistently achieve that level of performance. Third, it is well documented that nutrient loading capacity in the Spokane River is small. Finally, some companies now offer process guarantees of less than 50 g/L.[4]

There are two main parts to this memorandum. The first is a summary of previous reports on this subject. The second is an analysis of effluent data for wastewater plants achieving low effluent phosphorus concentrations. This analysis was performed in order to provide a more detailed profile of performance than is generally provided by the previous works summarized in Part 1. Also, I was able to locate two additional WWTPs that produce high quality effluent, which were not discussed in the sources referenced in Part 1.

As I explain below, I am aware of three existing, full-scale wastewater treatment plants which, based on past performance and previous reports, consistently achieve an average monthly concentration of 25 g/L, a total of five that consistently achieve an average monthly concentration of 35 g/L and a total of eight that consistently achieve an average monthly concentration of 50 g/L. There are isolated examples of even better performance.

Caveats

The majority of the available information on this subject concerns advanced treatment at publicly owned treatment works treating primarily domestic wastewater. Therefore, this memorandum is primarily relevant to these kinds of sources.

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[2] EPA's *Municipal Nutrient Removal Technologies Reference Document* (EPA 832-R-08-006, September 2008) provides some information about the costs of nutrient treatment and the available technologies. The Clean Water Act and its implementing requirements do not require a cost evaluation when establishing water quality-based effluent limits (CWA Section 301(b)(1)(C), 40 CFR 122.4(d), 122.44(d)).

[3] See memorandum dated September 14, 2005 from Ryan Orth of Ross and Associates to Len Bramble of the Washington Department of Ecology and Lars Hendron of the City of Spokane.

[4] See letter from Sean Haghighi, Vice President for Business Development, Veolia Water North America, to the Spokane County Board of County Commissioners, November 18, 2008. The letter refers to a process guarantee of 25 g/L; no averaging period is given.

The data gathered specifically for this memorandum and analyzed in Part 2, as well as most of the data summarized in other sources referenced herein, are from discharge monitoring reports (DMRs) submitted by NPDES permittees as required by their respective permits. DMRs have the advantage of being public information that is readily available for review. Also, one can be reasonably certain that data summarized on DMRs reflects the results of EPA-approved analytical methods and good quality assurance and quality control procedures. Furthermore, there are severe penalties for knowingly reporting false effluent data.

However, DMRs provide only a summary of the effluent data collected during a reporting period (typically a calendar month). Typically, a DMR will provide only the average and either the maximum daily or weekly concentration and loading for the month. This makes it difficult to determine the variability (e.g. standard deviation) of the effluent data. Different permitting authorities may have different policies regarding the inclusion of "non-detect" effluent data in monthly averages. This makes it difficult to quantify performance for facilities that discharge at concentrations near or below typical laboratory detection or quantification limits. Differences in sampling frequency among different facilities may also influence the DMR data.

As stated in other sources, some WWTPs are achieving effluent phosphorus concentrations that are far below their NPDES effluent limits. These facilities may be able to achieve better performance if their permits required it. The fact that effluent limits for many facilities are significantly higher than their performance contributes to the problem of insensitive analytical methods and "non-detect," results, because the permit provides no incentive for the discharger to use sensitive analytical methods if an analytical method providing a detection or quantification limit equal to or marginally less than the discharger's phosphorus effluent limit can be used to demonstrate compliance.

As has been noted elsewhere (*see* Reynolds and Clark, 2005) the facilities achieving the lowest effluent phosphorus concentrations tend to be relatively small. The largest facility discussed in this memorandum has a design flow of 4 million gallons per day (mgd). The technologies used to attain low effluent phosphorus concentrations at these small facilities (e.g. biological phosphorus removal, chemical addition, tertiary clarification, and filtration) can be scaled to larger facilities. However, larger facilities may face unique challenges. For example, the physical footprint of the scaled-up unit operations may be large. Also, it may be more difficult to maintain optimal operational parameters (e.g. volatile fatty acids, alkalinity, aeration/dissolved oxygen, chemical dosing, management of return streams from solids handling, etc.) at larger facilities. However, this does not necessarily mean that the level of performance demonstrated by these smaller facilities could not be achieved at larger facilities. Furthermore, with the exception of Spokane County and the City of Spokane, the POTWs discharging to the Spokane River have design flows no greater than 6 mgd (only 50% larger than the largest plant described herein).

The state of nutrient removal technology is changing and improving over time. This memorandum presents information regarding the performance of currently-operating facilities, with up to ten years of effluent data available, using proven technologies. Emerging or future technologies may provide better performance.

Part 1: Summary of Previous Reports

This is not an exhaustive review of available literature on this subject. This section does, however, summarize the findings of several recent and relevant reports on the subject of phosphorus removal.

EPA Publications

Municipal Nutrient Removal Technologies Reference Document (Office of Wastewater Management, September 2008)

The stated goal of the reference document is to "provide information that will assist local decision makers and regional and state regulators plan cost-effective nutrient removal projects for municipal wastewater treatment facilities."[5] The reference document addresses both phosphorus and nitrogen removal.

The overall conclusion of the reference document is that "(t)echnologies are available to reliably attain an annual average of 0.1 milligram per liter (mg/L) or less for (total phosphorus)…." See the reference document at Page ES-3. However, for watersheds such as the Spokane, which are very sensitive to phosphorus loading, it's necessary to know how much "less" than 0.1 mg/L (100 g/L) is, in fact, attainable.

The reference document provides some refinement of the attainable level of phosphorus removal in Section 2.6.3, where it states that "(s)pecial filters have proved effective in achieving low concentrations below 30 g/L. They include the Trident filter from U.S. Filter, the Dynasand D2 advanced filtration system from Parkson, and membrane filtration processes from various manufacturers."

The reference document mentions one facility (Brighton, Michigan) which meets a total phosphorus (TP) effluent concentration of 10 g/L consistently. The Brighton facility uses a treatment system that combines tertiary treatment with land application and which ultimately collects and discharges the land-applied wastewater through an underdrain system. Because this system uses soil for treatment and requires a large amount of land, (25 acres per mgd treated in Brighton's case) as a practical matter, it is very similar to wastewater land application or re-use. Therefore, the performance of the Brighton facility will not be further evaluated or discussed in this memorandum.

With the exception of the Brighton facility, the general finding of the reference document is that the best-performing technologies are capable of producing an annual average phosphorus concentration less than 30 g/L. Specific facilities achieving an annual average (50th percentile) concentration of about 30 g/L or less include the Pinery WWTP in Parker, Colorado (2 mgd design flow), the Lone Tree Creek WWTP in Centennial, Colorado (2.4 mgd design flow), and the Iowa Hill WWTP in Breckenridge, Colorado (1.5 mgd design flow). Based on a statistical analysis described in the reference document, these facilities had "maximum month" (92nd percentile) phosphorus concentrations of 61 ppb, 38 ppb, and 20 ppb, respectively. See the reference document at Table 2-5.

[5] The reference document can be downloaded from EPA's website at this address: http://www.epa.gov/owm/mtb/publications.htm

Advanced Wastewater Treatment to Achieve Low Concentration of Phosphorus (Region 10, April 2007)

The advanced wastewater treatment (AWT) report presents observations of advanced wastewater treatment at 23 facilities in the United States.[6] The overall finding of the AWT report is that "(c)hemical addition to wastewater with aluminum- or iron-based coagulants followed by tertiary filtration can reduce total phosphorus concentrations in the final effluent to very low levels. The total phosphorus concentrations achieved by some of these WWTPs are consistently near or below 0.01 mg/l" (see the AWT report at Page 3).

It is clear from the "Summary of Observations" table in the AWT report (Pages 7-8) that the 0.01 mg/L (10 g/L) figure stated on Page 3 is a reference to long-term average concentrations, not to maximum monthly average concentrations. The AWT report provides only the minimum, average, and maximum of the monthly averages observed; no other statistics are reported.

NPDES effluent limits are generally expressed as average monthly discharge limitations (meaning the maximum allowable arithmetic average concentration or loading measured during a calendar month). Thus, it is more consistent with the way effluent limits are generally expressed to quantify performance using a maximum monthly average value. The facilities described in the report that have maximum monthly average phosphorus concentrations of roughly 50 g/L or less are listed in Table 1, below.

Table 1: Best-performing WWTPs from *Advanced Wastewater Treatment to Achieve Low Concentration of Phosphorus*

Facility Name	Capacity (mgd)	Average of Monthly Average Phosphorus Concentrations (g/L)	Maximum Monthly Average Phosphorus Concentration (g/L)
Breckenridge S.D., Farmers Korner WWTP, Breckenridge, CO	3	7	36
Summit County Snake River WWTP, Dillon, CO	2.6	15	40
NYC DEP-Grand Gorge STP, Roxbury, NY	0.5	<40	50
Walton WWTP, NY	1.55	<10	<60
Stamford WWTP, NY	0.5	<11	<60

For this memorandum, I have used the AWT report as a screening tool to identify wastewater treatment plants for further data collection and analysis in Part 2.

[6] The report can be downloaded from EPA Region 10's website at this address: http://yosemite.epa.gov/r10/water.nsf/Water+Quality+Standards/AWT-Phosphorus

Non-EPA Publications

Achieving Low Effluent Total Phosphorus Concentrations: How Low Can We Go? (Stantec, Inc.)

Stantec is a large (10,000 employees) design and consulting firm headquartered in Edmonton, Alberta, Canada and founded in 1954.[7,8]

This white paper provides a review of the phosphorus removal capability of four WWTPs in the United States to assess the capability of full scale WWTPs to consistently achieve very low effluent TP concentrations, in response to proposals of effluent phosphorus limits less than 100 g/L in Ontario, Canada.

The four facilities described in the white paper were also included in EPA Region 10's AWT report, discussed above. These were the Breckenridge Sanitation District's Iowa Hill and Farmer's Korner WWTPs, the Summit Count Snake River WWTP (all in Colorado) and the Noman M. Cole Pollution Control Plant in Fairfax, Virginia. For each plant, the white paper provides a process description and a summary of effluent data. For the three Colorado facilities, the effluent data summary covers calendar years 2002, 2003, and 2004 in graphical form. In some cases the narrative discusses only a portion of the period of record shown on the graphs. The Noman M. Cole facility does not appear to be capable of achieving a monthly average phosphorus concentration of 50 g/L, therefore, I have not summarized its performance here. The performance of the other three facilities, as presented in the white paper, is summarized in Table 2, below.

Table 2: Summary of Performance Data Provided in *Achieving Low Effluent Total Phosphorus Concentrations: How Low Can We Go?*

Facility	Design Rated Capacity	Ratio of Actual Flow to Capacity	Average P Concentration and Period of Record	Maximum Month P Concentration and Period of Record
Iowa Hill WWTP	3 mgd	30%	8 g/L (2003-2004)	13 g/L (2003-2004)[a]
Farmer's Korner WWTP	3 mgd	45%	7 g/L (2003-2004)	12 g/L (2003-2004)[b]
Snake River WWTP	2.6 mgd	27%	18 g/L (2002-2004)	40 g/L (2002-2004)

Notes:
a. Figure 2 of the white paper shows a maximum monthly average P concentration of about 32 g/L in 2002.
b. Figure 4 of the white paper shows a maximum monthly average P concentration of about 32 g/L in 2002.

According to the white paper, all three of these facilities are operating at less than half of their design capacities. This may be a factor in these facilities' good performance.

Evaluation of Exemplary WWTPs Practicing High Removal of Phosphorus (Dave Reynolds, CH2MHILL and Dave Clark, HDR, November 21, 2005)

Ten facilities were included in this technical memorandum, including some of the facilities mentioned above. The technical memo includes data for the Stamford and

[7] Source: http://en.wikipedia.org/wiki/Stantec_Inc. (Accessed 3/3/09)
[8] Source: http://www.stantec.com/AboutUs.html (Accessed 3/3/09)

Walton, New York WWTPs mentioned above, however, it was later disclosed that the data presented for these facilities contained errors.[9] Corrected data were later provided to me in the form of a Microsoft PowerPoint presentation containing graphs of effluent data showing the lognormal mean, but not the coefficient of variation. The corrected lognormal means are shown in Table 3, below. One advantage of this report is that it summarizes individual sample results, as opposed to discharge monitoring reports.

The facilities profiled in the report (other than Stamford and Walton) with lognormal mean effluent TP concentrations less than 50 g/L are The Lone Tree WWTP in Centennial, Colorado, The Iowa Hill WWTP in Breckenridge, Colorado, and the Pinery WWTP in Parker, Colorado. The design flows listed in the technical memorandum are less than those of the same facilities as stated in the Stantec and EPA Region 10 reports discussed above, and as listed in EPA's permit databases. The reason for this discrepancy is unknown. Design flows listed in Table 3 are those stated in the Stantec and Region 10 reports described above or in NPDES permit databases.

Table 3, below, provides summary statistics for the effluent phosphorus concentrations of these facilities, as presented in the technical memorandum:

Table 3: Summary of Performance Data for Three WWTPs Provided in *Evaluation of WWTPs Practicing High Removal of Phosphorus*

Facility and Design Flow	Final Effluent Log Normal Average Total Phosphorus (g/L)		Log Normal Coefficient of Variation	
	Year 1	Year 2	Year 1	Year 2
Iowa Hill WWTP (1.5 mgd)	9	8	1.01	0.93
Lone Tree WWTP (2.4 mgd)	40	30	0.64	0.53
Pinery WWRF (2 mgd)	29	31	0.40	0.41
Stamford WWTP[a] (0.5 mgd)	12	8	Not Available	
Walton WWTP[a] (1.55 mgd)	8	7	Not Available	

Notes:
a. Performance data for the Stamford and Walton WWTPs was obtained from a PowerPoint presentation dated 8/16/06 and presented at the Advanced Treatment Process Evaluation Workshop. The COV was not provided.

It is possible to use the values in Table 3 to back-calculate the log transformed mean and variance (the mean and variance of the natural logarithms of the individual data points). The log transformed mean and variance of an effluent data set are the primary inputs to a spreadsheet tool developed by the Washington Department of Ecology, which is designed to calculate 95% confidence monthly average concentrations from historical effluent data for existing facilities.[10] The only other input to the tool is the sampling frequency. Table 4, below summarizes the 95% confidence monthly average concentrations for the facilities listed in Table 3, for sampling frequencies of 4 times per month (once per week), 8 times per month (twice per week) and 30 times per month (daily). A detailed derivation of these 95% confidence monthly averages is provided in Appendix A.

[9] Personal communication with James Tupper, Tupper Mack Brower 2/29/08.
[10] The spreadsheet tool can be downloaded from Ecology's website at the following address. This analysis used the PERFORMLIM spreadsheet in this workbook:
http://www.ecy.wa.gov/programs/eap/pwspread/tsdcalcAug08.xls

Table 4: 95% Confidence Monthly Average Concentrations for the Iowa Hill, Lone Tree, and Pinery WWTPs							
		Log Normal Mean (g/L)	Variance of Natural Logs	Mean of Natural Logs	95% Confidence Monthly Average Concentrations (g/L)		
Facility	COV				Daily Sampling	2x/week Sampling	1x/week Sampling
Iowa Hill WWTP year 1	1.01	9	0.70	1.8	12	15	18
Iowa Hill WWTP year 2	0.93	8	0.62	1.8	10	13	15
Iowa Hill WWTP Average					**11**	**14**	**16**
Lone Tree WWTP year 1	0.64	40	0.34	3.5	48	56	64
Lone Tree WWTP year 2	0.53	30	0.25	3.3	35	40	45
Lone Tree WWTP Average					**41**	**48**	**54**
Pinery WWRF year 1	0.4	29	0.15	3.3	32	36	39
Pinery WWRF year 2	0.41	31	0.16	3.4	35	39	42
Pinery WWRF Average					**34**	**38**	**41**

Spokane River TMDL Collaboration

There was a considerable data collection effort undertaken as part of the collaboration. A summary of the findings is provided in a memorandum dated September 14, 2005 from Ryan Orth of Ross and Associates to Len Bramble of the Washington Department of Ecology and Lars Hendron of the City of Spokane (the Orth memo).[11]

The Orth memo states that "(t)he (Technology Work Group) suggests at this time the Full Work Group consider utilizing 50 g/L (micrograms per liter) as an average monthly effluent concentration for total phosphorus possibly attainable by municipal wastewater treatment plants on an average monthly basis…."

The Orth memo includes a graphical summary of performance data for various WWTPs across the country. The graphs are box-and-whisker plots showing the minimum, 25th percentile, median, 75th percentile, 95th percentile and maximum monthly average effluent concentrations for 43 wastewater treatment plants. Table 5, below, shows the maximum and 95th percentile monthly average phosphorus concentrations for those facilities with a 95th percentile monthly average phosphorus concentration less than 50 g/L. These values are estimated from the box-and-whisker plot.

Table 5: WWTPs in the Orth Memo with a 95th Percentile Monthly Average Phosphorus Concentration Less Than 50 g/L			
Facility Name	**Capacity (mgd)**	**Approximate 95th Percentile Monthly Average Phosphorus Concentration (g/L)**	**Approximate Maximum Monthly Average Phosphorus Concentration (g/L)**
Stamford	0.5	17	21
Stonegate Village	1.1	35	Not Available
Walton	1.55	21	25
Pinery	2	42	47
Lone Tree Creek	2.4	48	51

I have used Mr. Orth's memorandum as a screening tool to identify wastewater treatment plants for further data collection and analysis in Part 2.

[11] The memorandum can be downloaded from the Spokane River TMDL Collaboration website at this address: http://www.client-ross.com/spokane-river/docs/Appendix%20B_Technology.pdf

Summary and Discussion of Part 1

The reports described above identify nine facilities that can consistently achieve low monthly average effluent phosphorus concentrations. These facilities are currently operating, full-scale wastewater treatment plants. Table 6, below, summarizes the maximum (or, in some cases, 95th percentile) monthly average phosphorus concentrations for all of the facilities mentioned above, as reported in or calculated from the references above:

Table 6: Summary of Maximum or 95th Percentile Monthly Average Phosphorus Concentrations

Facility	Design Flow (mgd)	Maximum Monthly Average Phosphorus Concentrations (in g/L) and reference(s)
Iowa Hill WWTP[a]	1.5	20 (EPA OWM, 2008) 32 (Stantec) 16 (Reynolds and Clark, 2005 and Appendix A) **Average: 23**
Farmer's Korner WWTP	3	36 (EPA Region 10, 2007) 32 (Stantec) **Average: 34**
Lone Tree Creek WWTP	2.4	38 (EPA OWM, 2008) 54 (Reynolds and Clark, 2005 and Appendix A) 51 (Orth, 2005) **Average: 48**
Snake River WWTP	2.6	40 (EPA Region 10, 2007) 40 (Stantec) **Average: 40**
Pinery WWTP	2	61 (EPA OWM, 2008) 74 (EPA Region 10, 2007) 41 (Reynolds and Clark 2005 and Appendix A) 42 (Orth, 2005) **Average : 55**
Stamford WWTP[b]	0.5	**21** (Orth, 2005)
Walton WWTP[b]	1.55	**25** (Orth, 2005)
NYC DEP Grand Gorge STP	0.5	**50** (EPA Region 10, 2007)
Stonegate Village WWTP	1.1	**35**[c] (Orth, 2005)
Median for Above Facilities	**N/A**	**35**

Notes:
a. The EPA Region 10 AWT report lists the maximum monthly average concentration for the Iowa Hill WWTP as 130 g/L. Since three other references state that the maximum monthly average for this is an order of magnitude lower, the Region 10 value was not considered in the average. The discrepancy is likely due to the fact that the Iowa hill facility is not required to report monthly average phosphorus concentrations on DMRs; it is only required to report the maximum daily phosphorus concentration. It appears from a review of DMR data for the Iowa Hill facility that the values in the AWT report represent daily maximum values, not average monthly values.
b. The Stamford and Walton facilities are also mentioned in the EPA Region 10 (2007) and Orth documents, but the maximum monthly average concentration is given as a "less than" value (see Table 1).
c. 95th Percentile

These values may, in some cases, represent pessimistic estimates of the levels of phosphorus removal that are consistently achieved. For example, while I have used 32 g/L as the maximum monthly average phosphorus concentration from the Stantec white paper for the Iowa Hill and Farmer's Korner WWTPs in Table 6, these facilities were

able to consistently achieve maximum monthly average phosphorus concentrations less than 15 g/L for a two year period (see Table 2, above).

Table 6 shows that the nine high-performing facilities described above consistently achieve monthly average phosphorus concentrations between about 21 and 55 g/L, with a median of 35 g/L. In other words, of these nine facilities, it appears from the information provided in the documents referenced above that five consistently achieve a concentration of 35 g/L (Stonegate Village, Stamford, Walton, Farmer's Korner, and Iowa Hill).

Part 2: Analysis of Effluent Data

For each of the nine facilities listed in Table 6, above, I attempted to obtain effluent (DMR) data from EPA's computer databases, the Permits Compliance System (PCS) and the Integrated Compliance Information System (ICIS). These data are available to the public through EPA's web-based Envirofacts Warehouse.[12] I was able to obtain meaningful effluent data for all but the Iowa Hill facility, which only reports a maximum daily concentration for the month, and the total annual phosphorus load (pounds per year). However, I was also able to obtain effluent data for two additional WWTPs exhibiting performance similar to those listed in Table 6 (the Indian River County Utilities West Regional WWTF in Vero Beach, Florida and the Parker Water and Sanitation District WWTP in Parker, Colorado). Design flows of these facilities range from 0.5 to 4.0 mgd.

Table 7 provides summary statistics (percentiles, averages) and the percentage of the time the average monthly concentrations are less than or equal to certain concentrations, as well as the required sampling frequency (if known), for each facility.

Discussion

Changes in Effluent Limits and Outlying Values

If a stringent phosphorus effluent limit took effect in a facility's permit at a certain time, in some cases, I restricted the data that I included in the analysis to the period of time during which stringent effluent limits were applicable. If the effluent quality did not appear to change as a result of the new effluent limit, I did not exclude data collected when stringent limits did not apply.

Prior to any further analysis, a plot of the monthly average data over time was prepared for each facility. Data points that appeared to be outlying values were subjected to a Grubb's extreme value test.[13] Data points that were determined to be statistical outliers at a 99% confidence level were discarded prior to any further analysis.

If there was a long period of time during which performance appeared to be significantly better than at other times, I performed a t-test to determine if the performance during that time was statistically distinct from that at other times. If the performance was statistically distinct, I included only the data for the time when better performance was

[12] The URL for the Envirofacts Warehouse is http://www.epa.gov/enviro/.
[13] For a description of the Grubb's test, see http://www.graphpad.com/quickcalcs/GrubbsHowTo.cfm.

observed in the analysis. In every case except Stonegate Village Metro District, the data summarized below nonetheless represent a period of record of at least 36 consecutive months.

Exclusion of certain data from analysis is discussed in detail in Appendix B. Results of the statistical tests justifying the exclusion of certain data are available upon request.

"Less Than" and Zero Substitutions

Monthly average data for certain facilities were sometimes reported as "less than" a certain value. Also, I assumed that a reported monthly average of zero meant that all values measured during the month were less than the analytical detection or quantification limit.

For monthly averages reported as "less than" a certain value, I assumed that these values were equal to the reported "less than" value. For example, if the value reported for a given month was "< 30 g/L," I assumed the monthly average concentration was actually 30 g/L, even though it is known to be less than that. For monthly averages reported as zero, I substituted the lowest nonzero value reported for that facility.

Both of these assumptions will make the average performance of a given facility appear to be poorer than it actually is. However, these assumptions will have little to no effect on the upper percentile (75th, 90th and 95th percentile) monthly average phosphorus concentrations for a given facility, unless nearly all of the values were reported as "less than" or zero (which was the case for Walton facility). A discussion of the treatment of "less than" and zero data for each facility is provided in Appendix B.

Quantifying Performance

I have identified the 95th percentile monthly average phosphorus concentration as the concentration that is consistently achieved by each facility. By definition, this means that the monthly averages were greater than this value 5% of the time. Since any violation of an effluent limit in an NPDES permit is a violation of the Clean Water Act, an argument could be made for using the maximum monthly average value instead of the 95th percentile, however, I believe the use of the 95th percentile is appropriate for the following reasons:

- A facility that achieves compliance with an effluent limit 95% of the time would likely be a low priority for an enforcement action, particularly for a stringent effluent limit for a non-toxic chemical. Repeated violations and violations of effluent limits for toxic chemicals would generally have a higher enforcement priority.
- In general, these facilities are achieving a level of performance that is much lower than the effluent limits in their permits (which are often greater than 100 g/L). Facilities with permitted effluent limits that are large relative to their average performance have no incentive to consistently achieve the best possible performance. If a facility's effluent limits were more stringent (e.g. if the limit were close to the facility's 95th percentile discharge) the facility may be able to find and correct the cause of infrequent excursions significantly above the facility's average performance. Using the maximum monthly average concentration to quantify performance instead

of the 95th percentile would mask the fact that performance is much better than the maximum monthly average, the vast majority of the time.

- In the context of determining whether a POTW is eligible for "treatment equivalent to secondary" technology-based effluent limits for BOD_5 and TSS, NPDES regulations define the 95th percentile as the "effluent concentration consistently achievable through proper operation and maintenance" (40 CFR 133.101(f)).

Other measures of performance, including maximum monthly average values, are provided for information purposes in Table 7. A discussion of each facility's data is provided in Appendix B.

Results of Part 2

The effluent data analysis in Part 2 is in general agreement with the previous reports summarized in Part 1. Two exceptions are the Stonegate Village Metro District WWTP and the Lone Tree Creek WWTP; Table 7 shows somewhat poorer performance than that estimated by previous reports for those two facilities (50 g/L as opposed to 35 g/L for Stonegate Village and 60 g/L as opposed to 48 g/L for Lone Tree). Conversely, Table 7 shows the performance of the Pinery WWTP may be somewhat better than that estimated by previous reports (47 g/L as opposed to 55 g/L). The phosphorus concentrations consistently achieved by the facilities listed in Table 7 (as quantified by the 95th percentile values) range from 22 – 60 g/L.

With the exception of the Grand Gorge facility, long term average performance for all facilities is 32 g/L or less. The Grand Gorge average is skewed upward by insensitive analytical methods and conservative handling of "less than" and zero values. The overall average performance of these exemplary facilities is 26 g/L. This shows that, in order to consistently achieve low effluent phosphorus limits, the long term average discharge must be considerably less than the monthly average effluent limit.

Four of the ten facilities listed in Table 7 (Stamford, Walton, Farmer's Korner, and Parker W&S) achieve a monthly average effluent concentration of 35 g/L more than 95% of the time, based on past performance. An additional facility (Indian River County Utilities) may be able to achieve a concentration of about 35 g/L, if effluent variability was reduced (the 90th percentile discharge for this facility was 30 g/L).

Table 7: Analysis of Effluent Phosphorus Data											
Facility Name	**Farmer's Korner WWTP**	**Lone Tree Creek WWTP**	**Summit County Snake River WWTP**	**Pinery WWRF**	**Parker Water and Sanitation District WWTP**	**Indian River County Utilities West Regional WWTF**	**Walton WWTP**	**Stamford WWTP**	**New York City DEP Grand Gorge STP**	**Stonegate Village Metro District WWTP**	**Combined Data for All Facilities**
Location	Breckenridge, Colorado	Centennial, Colorado	Dillon, Colorado	Parker, Colorado	Parker, Colorado	Vero Beach, Florida	Walton, New York	Stamford, New York	Roxbury, New York	Parker, Colorado	
NPDES Permit #	CO0021539	CO0040681	CO0029955	CO0041092	CO0046507	FL0041637	NY0027154	NY0021555	NY0026565	CO0040291	
Design Flow (mgd)	3	2.4	2.6	2	3.5	4	1.55	0.5	0.5	1.1	
Phosphorus Sampling Freq.	Twice per Week	Twice per Week	Twice per Week	Twice per Week	Once per Week	Once Per Week	Unknown	Unknown	Unknown	Once per Week	
Phosphorus Conc. Limits[a]	500 g/L MDL	50 – 200 g/L AML	500 g/L MDL	50 – 200 g/L AML	50 g/L AML	125 g/L AML	200 g/L AML	150 – 200 g/L AML	200 g/L AML	50 – 250 g/L AML	
Period of Record for Phosphorus Data	3/2000 – 4/2006	1/2001 – 1/2009	1/1998 – 7/2008	1/2001 – 6/2008	8/2004 – 6/2008	3/2002 – 4/2005	2/2003 – 6/2006	2/2003 – 6/2006	4/1999 – 6/2006	8/2004 – 12/2006	
Monthly Average Phosphorus Concentration Statistics											
Minimum	2	10	6	15	15	10	5	5	40	20	2
Median	11	30	10	26	28	20	8	9	42	28	22
Average	14	32	17	29	25	25	10	10	46	30	26
75th Percentile	20	43	20	34	29	30	11	11	50	40	38
90th Percentile	31	53	30	41	31	30	15	14	50	50	50
95th Percentile	**32**	**60**	**37**	**47**	**34**	**60**	**23**	**22**	**52**	**50**	**50**
Maximum	39	80	70	60	49	150	44	40	100	60	150
Concentration (g/L)	**% of Time Less Than or Equal To**										
10	49%	8%	56%	0%	0%	38%	73%	65%	0%	0%	26%
20	76%	27%	87%	9%	26%	69%	93%	93%	0%	47%	47%
30	89%	53%	94%	66%	83%	91%	98%	98%	0%	62%	68%
40	100%	71%	97%	89%	96%	91%	98%	100%	48%	85%	84%
50	100%	88%	99%	99%	100%	91%	100%	100%	93%	97%	96%
60	100%	98%	99%	100%	100%	97%	100%	100%	98%	100%	99%

Notes:
a. "MDL" means "maximum daily discharge limitation" and "AML" means "average monthly discharge limitation" as those terms are defined in 40 CFR 122.2. Other limits apply in most cases (e.g. loading limits and/or additional concentration limits with different averaging periods).

Overall Results

It appears from the information presented above that a concentration of 50 g/L is more than "possibly attainable by municipal wastewater treatment plants," which was the conclusion of the Spokane River TMDL Collaboration Technology Workgroup in 2005. There are at least eight operating, full scale facilities that consistently produce effluent of this quality and better (see Figures 1 and 2, below). Furthermore, some facilities have a currently effective AML of 50 g/L in their NPDES permits (Lone Tree, Parker W&S District, Pinery, and Stonegate Village).

Considered together, Parts 1 and 2 show that existing WWTPs are consistently achieving monthly average phosphorus concentrations in the range of 21 to 60 ppb. There are a few examples of even better performance (e.g. the 2003 – 2004 time frame for Iowa Hill and Farmer's Korner, see Table 2), but it is unclear whether that level of performance would generalize to other facilities or longer time frames.

Based on past performance, three of the eleven WWTPs evaluated could consistently achieve a monthly average phosphorus concentration of 25 g/L. These are: Stamford, Walton, and Iowa Hill (see Figure 2, below). Two additional facilities (Farmer's Korner and Parker Water and Sanitation District, a total of five) could consistently achieve a concentration of 35 g/L, and an additional facility (Indian River County Utilities) may be able to achieve a concentration of 35 g/L if its effluent were less variable. Three additional facilities could consistently achieve a phosphorus concentration of 50 g/L (Snake River, Pinery and Stonegate Village, a total of eight). The 95th percentile for all of the phosphorus data analyzed in Part 2 is 50 g/L. Figures 1 and 2, below, provide graphical representations of the results presented in Tables 6 and 7.

Other facilities achieving low phosphorus levels may exist that were not included in this analysis. Since only four of the eleven facilities discussed have effluent limits of 50 g/L, and none have effluent limits less than 50 g/l, the results may not represent levels which could be achieved if attempts were made to further optimize phosphorus removal. Furthermore, phosphorus removal technology is likely to improve over time.

Figure 1

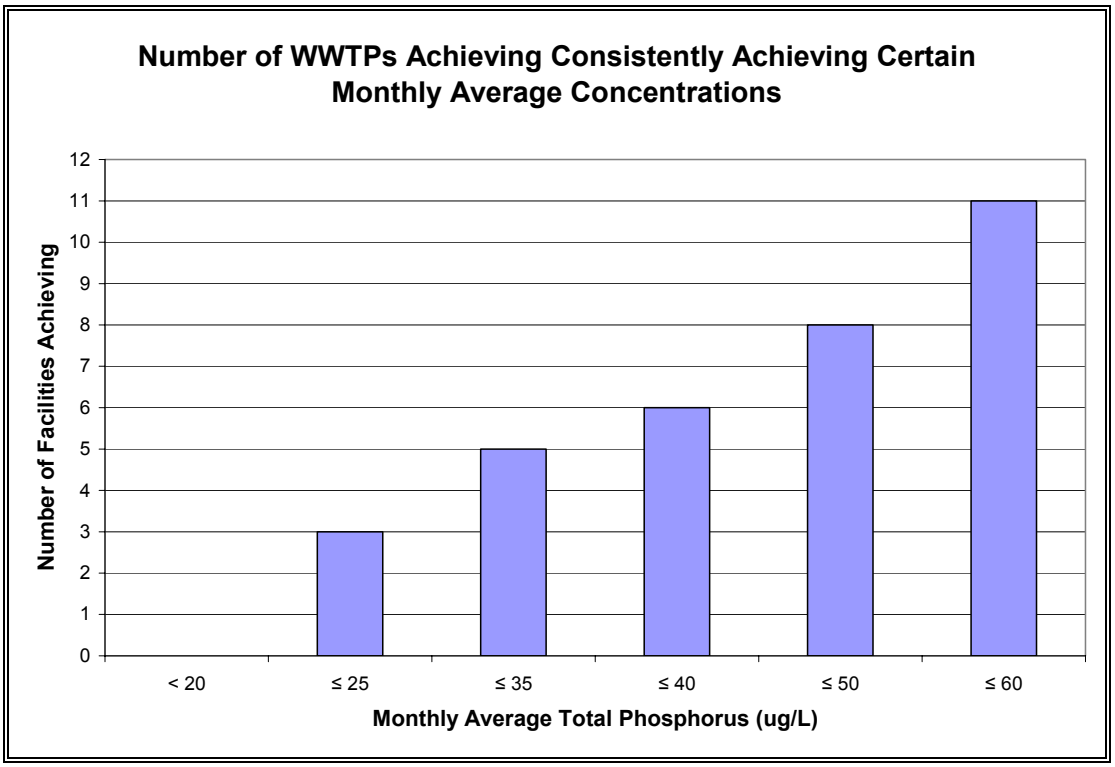
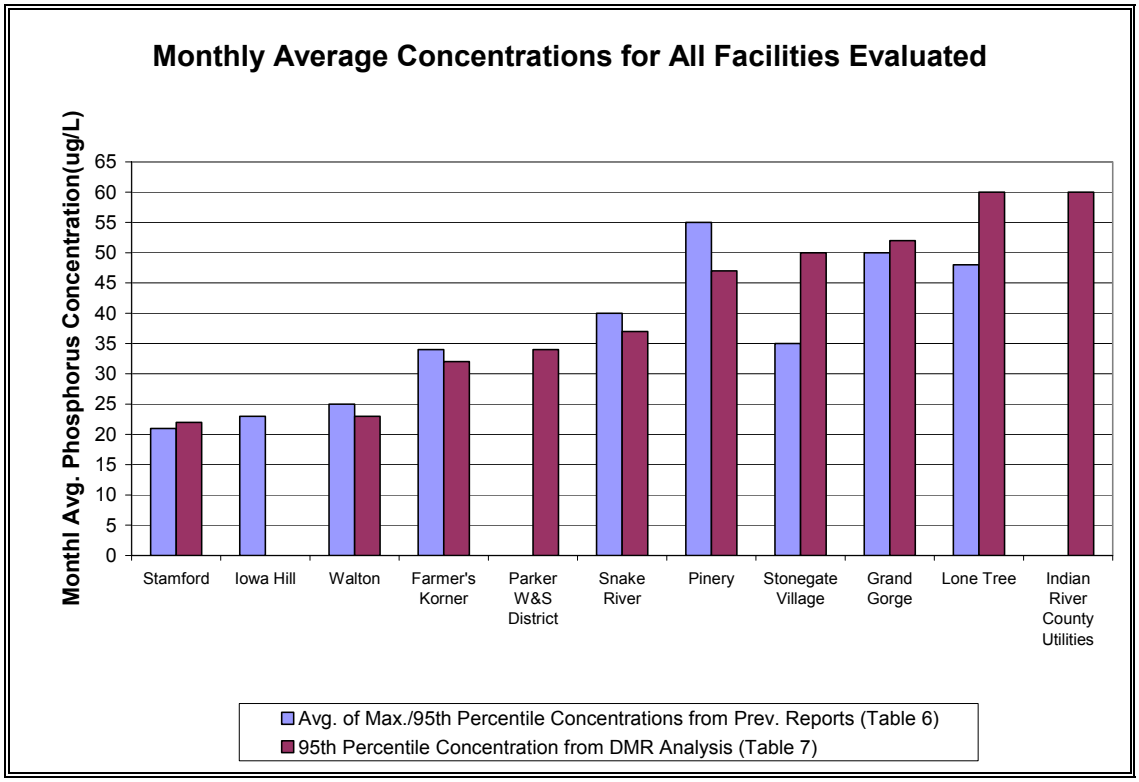


Figure 2



Appendix A: Calculation of 95% Confidence Maximum Month Concentrations from *Evaluation of Exemplary WWTPs Practicing High Removal of Phosphorus*

Overview

The *Evaluation of Exemplary WWTPs practicing High Removal of Phosphorus* (Reynolds and Clark, 2005) is a technical memorandum which provides information regarding the performance of wastewater treatment plants that produce low effluent phosphorus concentrations. The memo characterizes the performance of WWTPs using the "log normal average" and the "log normal coefficient of variation."

While these values provide the central tendency of the effluent data and a measure of how variable the data are, they do not directly provide the maximum monthly average concentrations that these facilities might be able to achieve. However, these values do provide the basis to calculate expected "maximum month" concentrations, as explained below.

Calculation of the Log Normal Average and Standard Deviation

The "log normal" average and coefficient of variation were calculated using the following general procedure.[1] See also the *Technical Support Document for Water Quality-based Toxics Control* (EPA 505/2-90-001), hereinafter referred to as the TSD, at Page E-8.[2]

- A log transformation of the facility's effluent data was prepared, meaning, the natural logarithms of the measured phosphorus concentrations were calculated.
- The average, variance, and standard deviation of the log-transformed data were calculated.
- The log normal average was calculated from the using the formula for the mean (or expected value, "E") of a lognormally distributed variable, which is:

  $$Mean = E(X) = e^{\mu+\sigma^2/2} \qquad \text{(Equation 1)}$$

  Where:

  E is the expected value (log normal mean)
  X is a lognormally distributed variable
  μ is the mean of the variable's natural logarithm,
  σ is the standard deviation of the variable's natural logarithm, and
  σ^2 is the variance of the variable's natural logarithm.

- The coefficient of variation (CV) is equal to the standard deviation divided by the mean.[3] The log normal coefficient of variation was calculated using the following

[1] Personal communication with Dave Clark, HDR, Inc., 3/17/09 and 3/19/09.
[2] The TSD can be downloaded from EPA's website at this address:
http://www.epa.gov/npdes/pubs/owm0264.pdf
[3] See TSD at Page xx.

formula, which is the quotient of the formulae for the standard deviation and the mean of a lognormally distributed variable:[4]

$$CV = \sqrt{(e^{\sigma^2} - 1)} \qquad \text{(Equation 2)}$$

Back-Calculation of the Mean and Variance of the Log-Transformed Data

The log transformed mean and variance of an effluent data set (i.e. the mean and variance of the natural logs of an effluent data set) are the primary inputs to a spreadsheet tool developed by the Washington Department of Ecology, which is designed to calculate the 95% confidence monthly average concentration from historical effluent data for existing facilities.[5] The only other input to the tool is the sampling frequency.

To back-calculate the variance of the log-transformed data, I solved equation 2, above, for the variance (σ^2). This yields:

$$\sigma^2 = \ln(CV^2 + 1) \qquad \text{(Equation 3)}$$

To back-calculate the mean of the log-transformed data, I solved equation 1, above, for the log-transformed mean ( ). This yields:

$$\mu = \ln(E(X)) - \frac{\sigma^2}{2} \qquad \text{(Equation 4)}$$

Where E(X) is the log-normal mean.

Since the log transformed mean is a function of the log transformed variance, I calculated the variance first, using equation 3. Once the variance was known, I calculated the log-transformed mean.

For example, for the "year 1" values for the Pinery WWTP, the CV is 0.40, and the log normal mean (E(X)) is 29 g/L. Thus:

$$\sigma^2 = \ln(CV^2 + 1) = \ln(0.4^2 + 1) = \ln(1.16) = 0.148$$

And:

$$\mu = \ln(E(X)) - \sigma^2 / 2 = \ln(29) - 0.148/2 = 3.29$$

The results of these calculations, for the Pinery, Iowa Hill, and Lone Tree WWTPs are provided in Table 1, below:

[4] See TSD at Page E-8 and http://en.wikipedia.org/wiki/Log-normal_distribution.

[5] The spreadsheet tool can be downloaded from Ecology's website at the following address: http://www.ecy.wa.gov/programs/eap/pwspread/tsdcalcAug08.xls. See also the instructions for its use: http://www.ecy.wa.gov/programs/eap/pwspread/sprdshts.doc

Table 1: Back-Calculated Log Transformed Mean and Variance				
Facility	**COV**	**Log Normal Mean (g/L)**	**Variance of Natural Logs**	**Mean of Natural Logs**
Iowa Hill WWTP year 1	1.01	9	0.703	1.85
Iowa Hill WWTP year 2	0.93	8	0.623	1.77
Lone Tree WWTP year 1	0.64	40	0.343	3.52
Lone Tree WWTP year 2	0.53	30	0.248	3.28
Pinery WWRF year 1	0.4	29	0.148	3.29
Pinery WWRF year 2	0.41	31	0.155	3.36

These values were then input into the spreadsheet tool, which calculates the average monthly concentration that is achievable with 95% confidence, based on the log transformed mean and variance, and the sampling frequency, using the procedures described in Appendix E of the TSD. The results are provided in Table 4 of the body of this memorandum. The spreadsheets are available upon request.

Appendix B: Discussion of Individual Facility Data Sets

This is a discussion of the data for each individual facility evaluated in Part 2 of the body of this memorandum. The charts below reflect the same data summarized in Table 7 of the body of this memorandum, meaning they reflect the rejection of outliers and substitutions for less than and zero values, as described in the narrative for each facility, below.

Farmer's Korner WWTP

The treatment process for this facility is described on Page 17 of the 2007 EPA Region 10 AWT report. Between March of 2000 and April of 2006 (a span of 6 years and 2 months) the facility did not report a single monthly average effluent phosphorus concentration greater than 40 g/L. The March 2000 – April 2006 period was statistically distinct from other time periods. Therefore, further calculations considered only the data collected between March 2000 and April 2006, a period spanning six years and two months (74 data points). Furthermore, as shown in Table 2, above, the facility's maximum monthly average phosphorus concentration during calendar years 2003 and 2004 was 12 g/L.

Based on the 95th percentile of past performance, it appears that the Farmer's Korner facility could consistently achieve a concentration of about 32 g/L, consistent with previous reports (see Table 6, above).

Figure 1

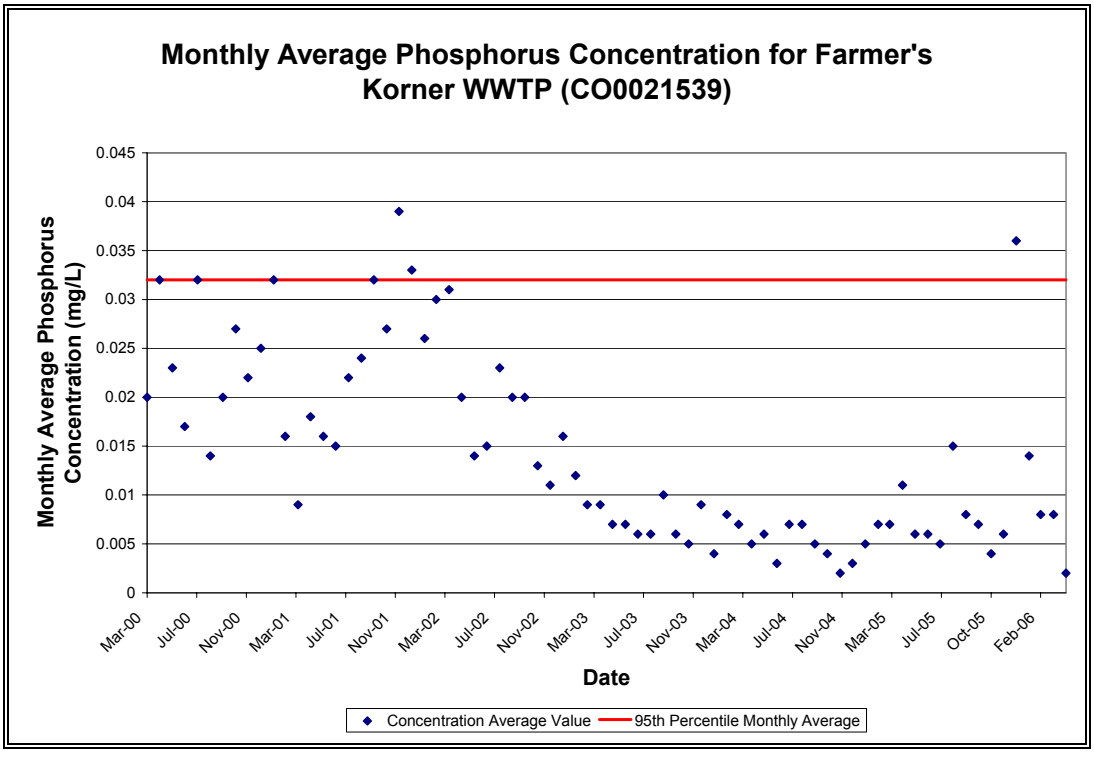
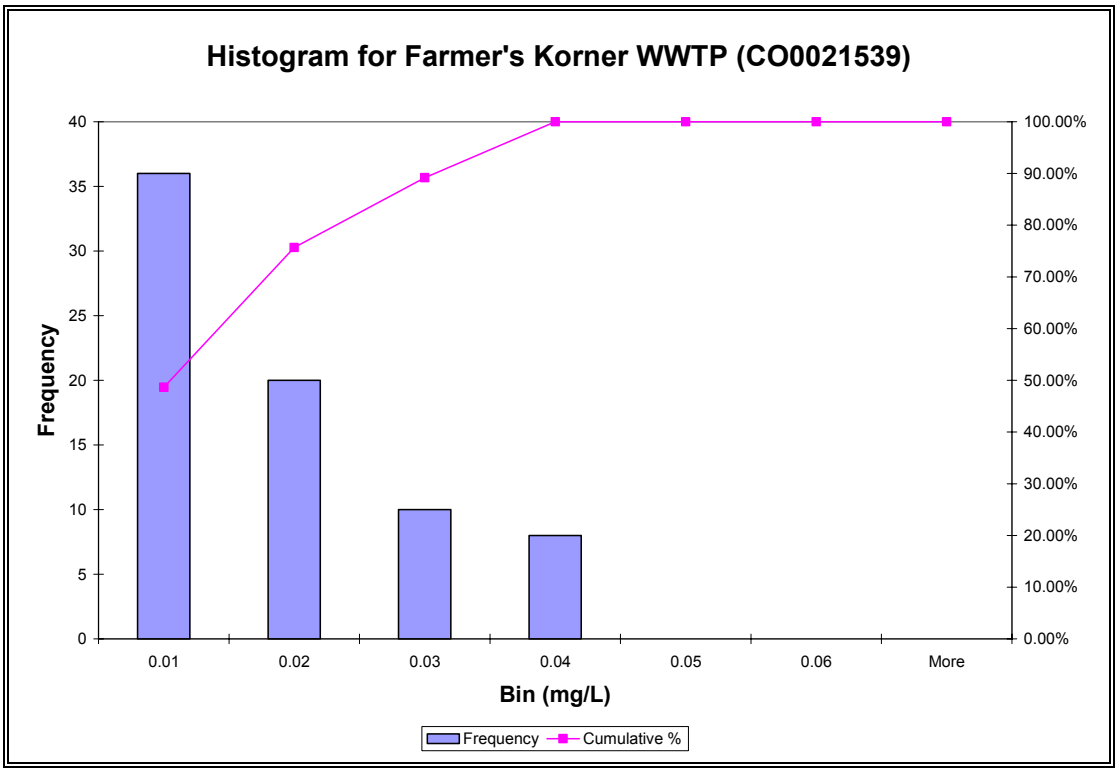


Figure 2



Lone Tree Creek WWTP

The treatment process for this facility consists of chemical addition (ferric chloride) and a membrane bioreactor using Zenon membranes.[1] One data point (4.2 mg/L measured during May 2000) was discarded based on a Grubb's extreme value test. A t-test showed that the data prior to 2001 (with the May 2000 outlier discarded) were statistically distinct from the data collected after January 1, 2001. Therefore, further calculations considered only the data collected after January 1, 2001.

A 30-day average AML of 50 g/L went into effect in January of 2006. The facility has violated the 50 g/L AML four times in the three years since it was imposed (July, August, and November 2007, and January 2009). This represents compliance with the limit 89% of the time. The data reported after January 1, 2001 and before the 50 g/L limit was imposed (in January 2006) was not statistically distinct from that collected after the 50 g/L limit was imposed. Therefore, the data collected after the 50 g/L limit took effect have not been analyzed separately from the data collected prior to the 50 g/L limit taking effect. Prior to the time that the 50 g/L limit was imposed, for some monitoring periods, more than one average monthly phosphorus value was reported. The reason for this is unknown; no data have been excluded because of this. Of the 147 monthly average phosphorus concentrations reported after January 1, 2001, nine were reported as zero. The lowest nonzero value reported was 10 g/L; this value was substituted for the zero values.

[1] See the *Evaluation of Exemplary WWTPs Practicing High Removal of Phosphorus* (Reynolds and Clark, 2005) at Pages 5 and 16.

Based on the 95th percentile of past performance, it appears that the Lone Tree Creek facility may have difficulty complying with a monthly average effluent phosphorus limit of 50 g/L. A monthly concentration of about 60 g/L appears to be consistently achievable for this facility, which is somewhat poorer than previous reports (Table 6).

Figure 3

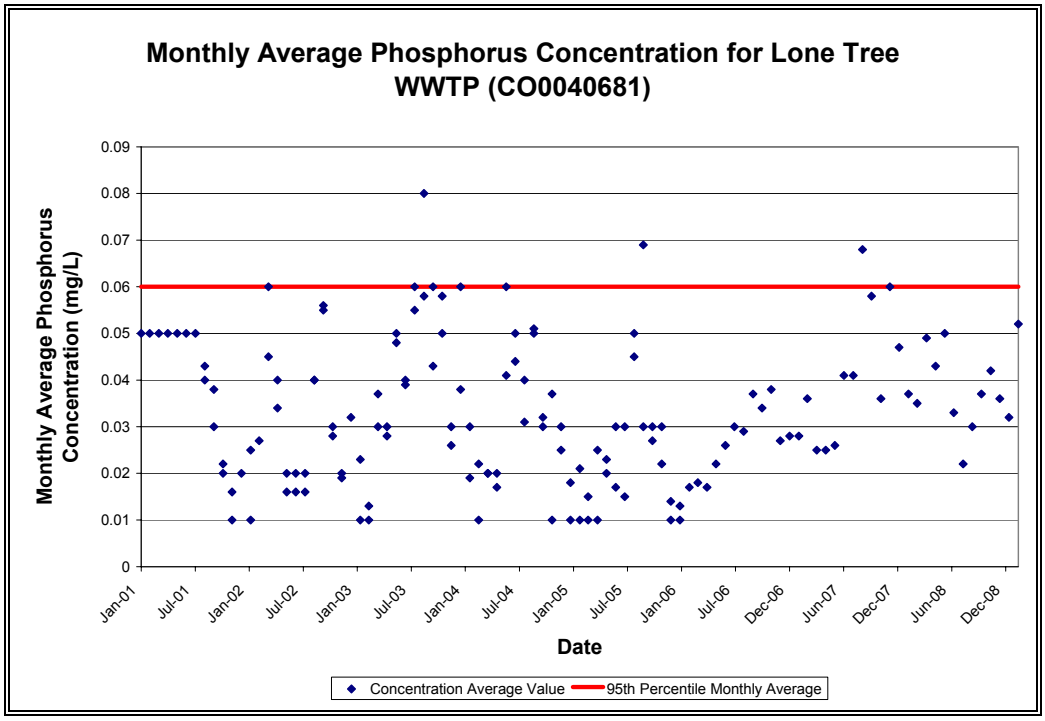
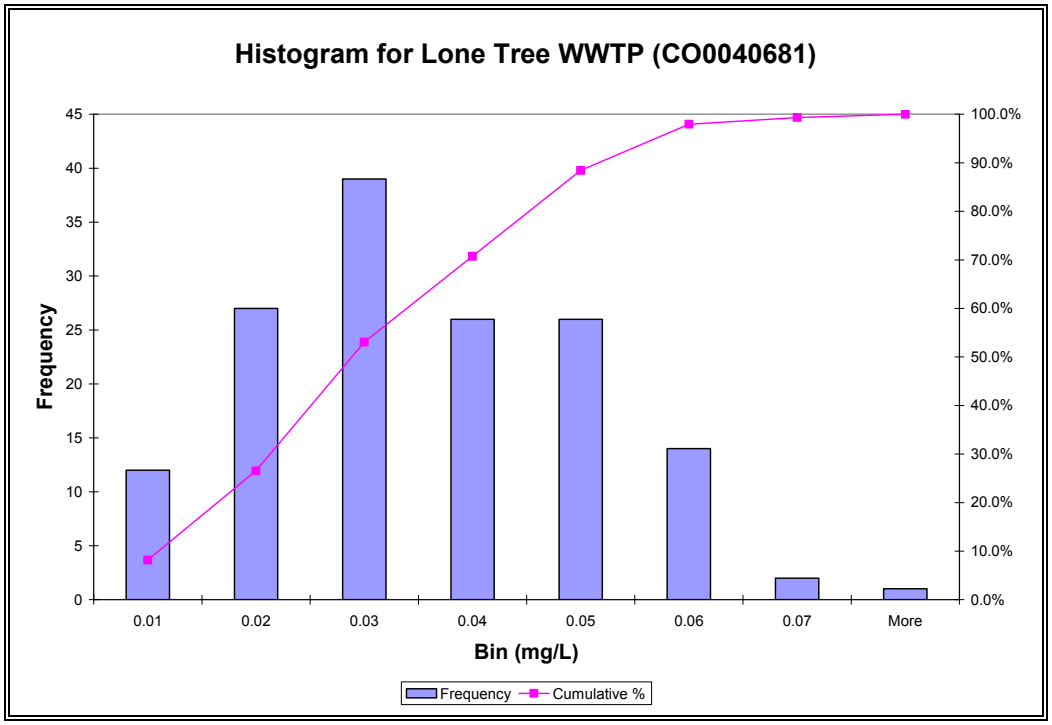


Figure 4



Snake River WWTP

The treatment process for this facility is described on Page 19 of the 2007 EPA Region 10 AWT Report. The performance of this facility was very consistent over the 10 year and 7 month period for which effluent data were available (127 data points). No data were reported as zero or less than values, and no outlying values were excluded from the calculation. Based on the 95th percentile of past performance, it appears that this facility could consistently achieve a concentration of 37 g/L, which is consistent with previous reports (Table 6).

Figure 5

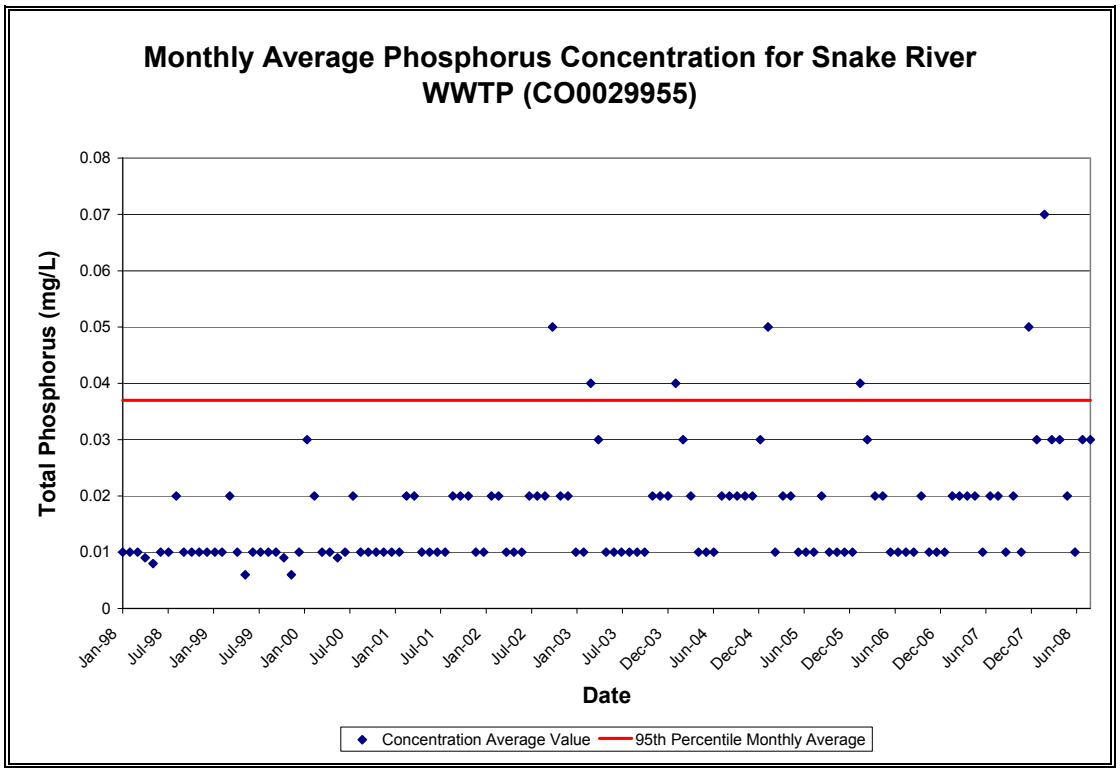
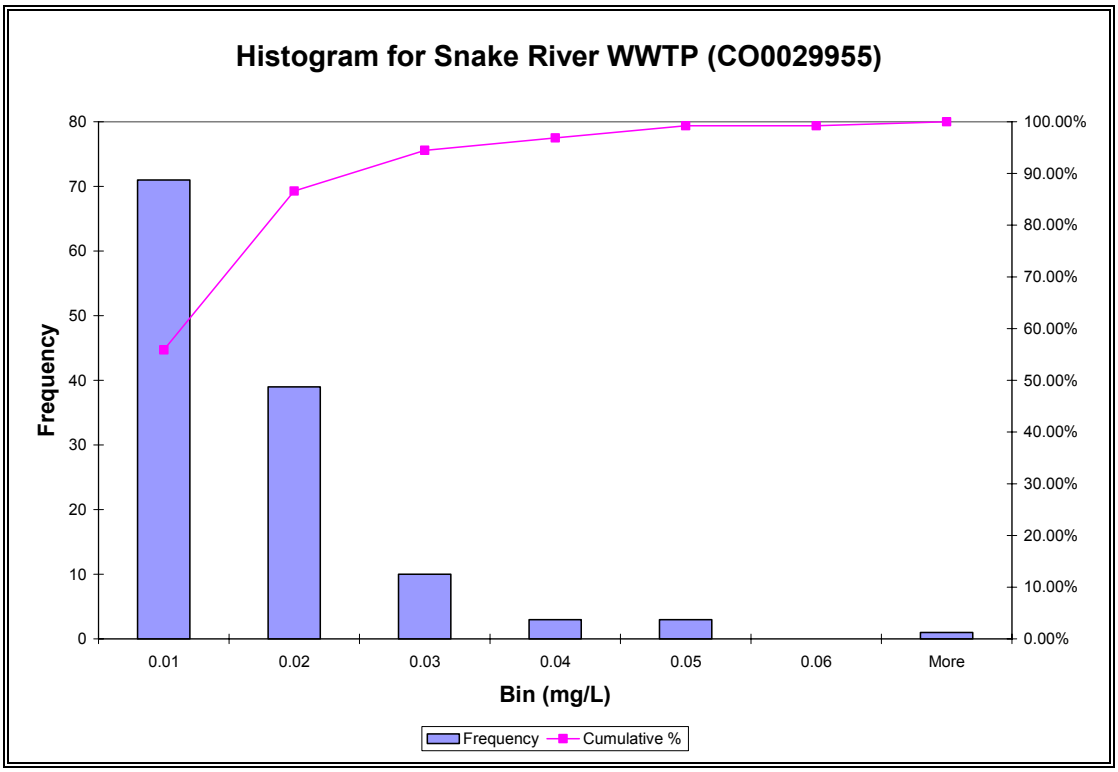


Figure 6



Pinery WWTP

The treatment process for this facility is described on Page 22 of the 2007 EPA Region 10 AWT Report. Effluent data collected prior to January 1, 2001 were statistically distinct from later effluent data and were excluded from further analysis. One outlying data point among the data collected after January 1, 2001 was discarded based on a Grubb's extreme value test. No data were reported as zero or less than values. After excluding data collected prior to 2001 and the outlying value, 89 data points remained. Based on the 95th percentile of past performance, it appears that this facility could consistently achieve a concentration of about 47 g/L, which is somewhat better than previous reports (Table 6).

Figure 7

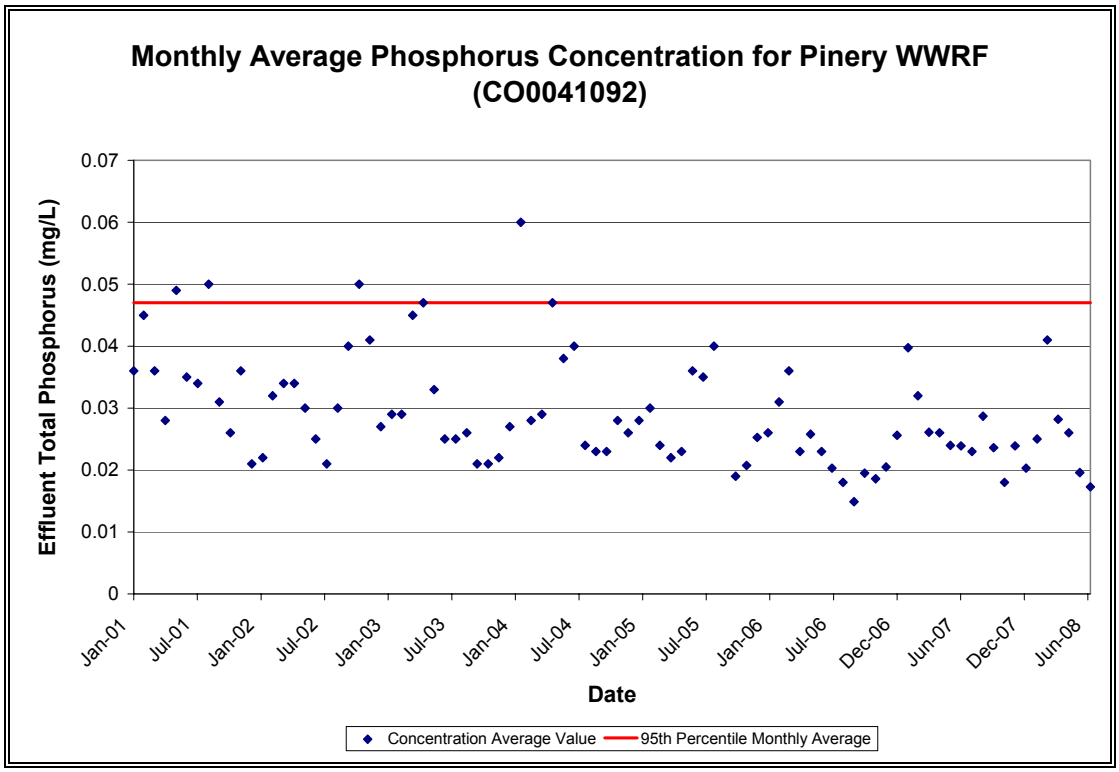
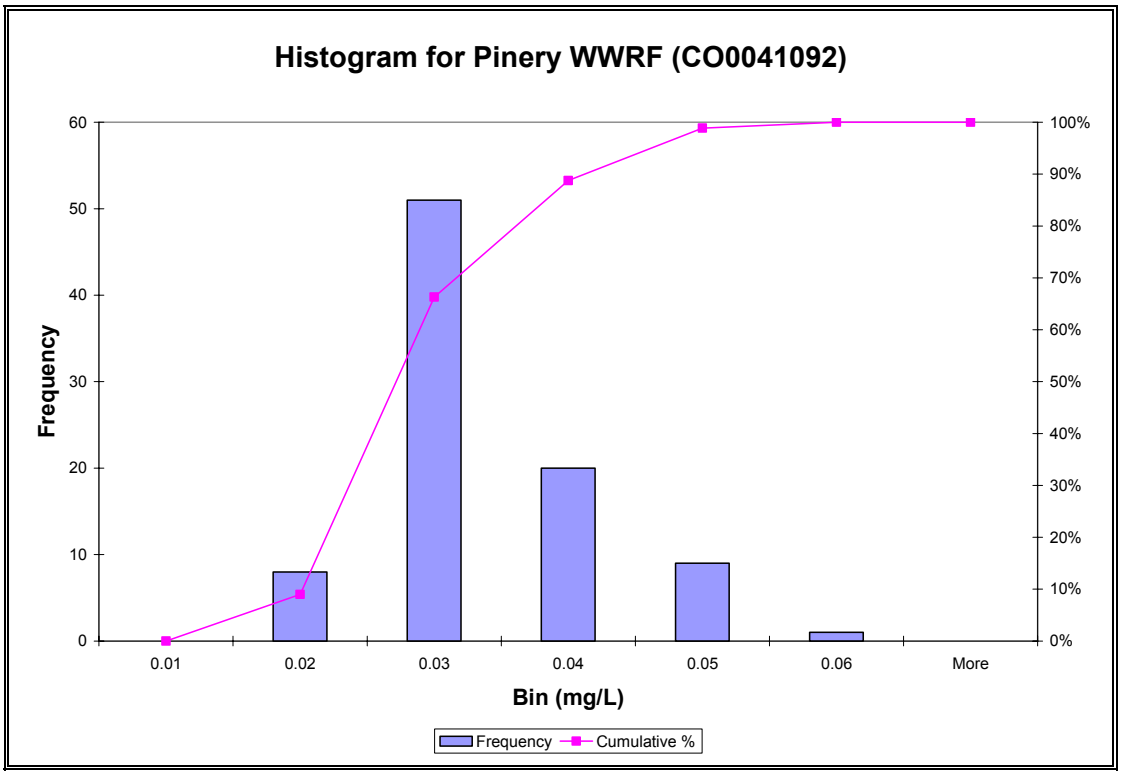


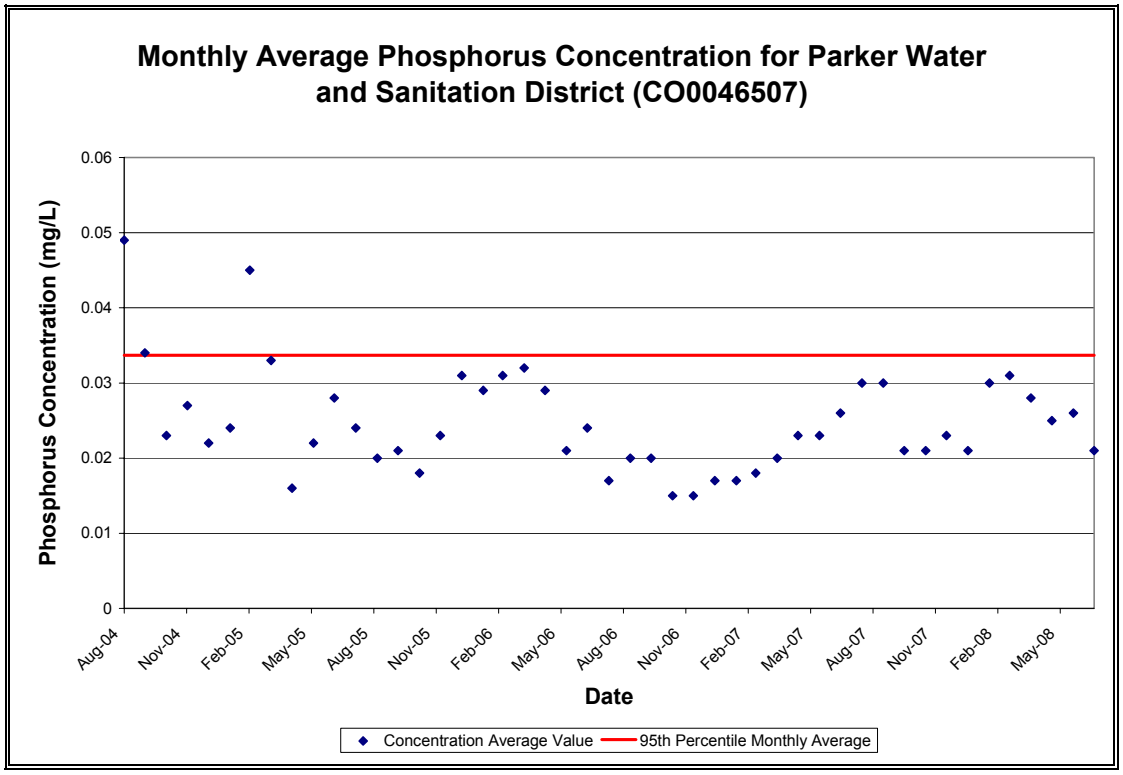
Figure 8



Parker Water and Sanitation District WWTP

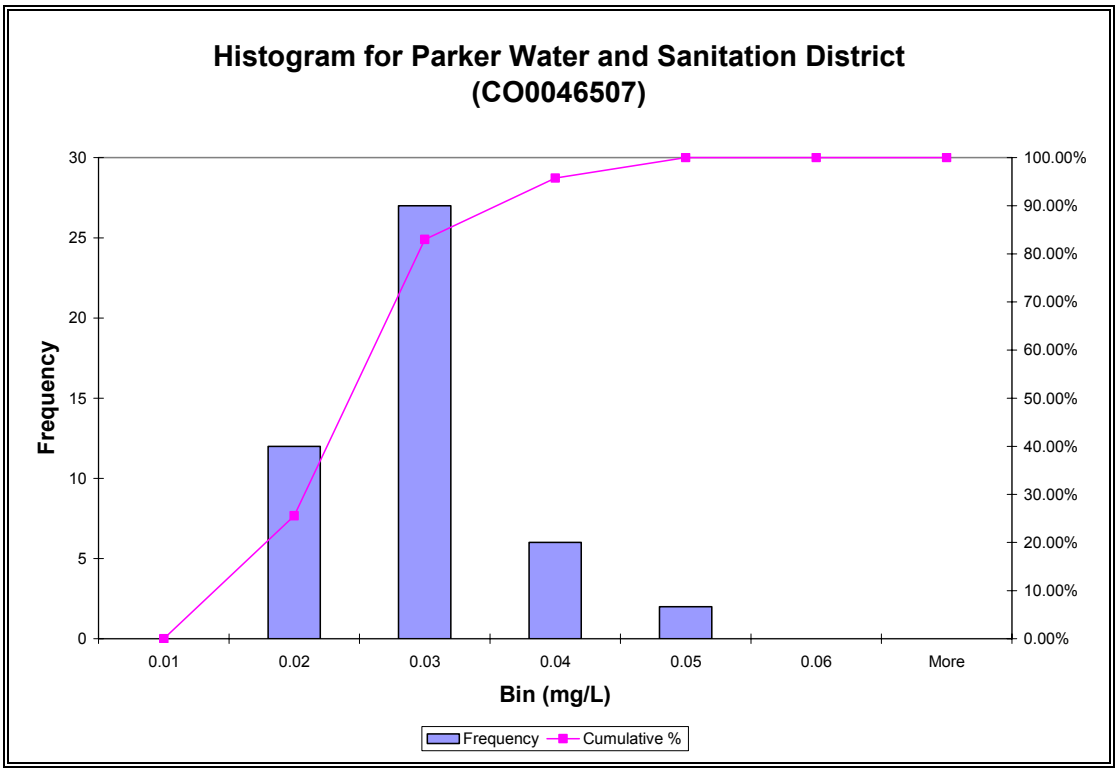
Treatment processes at this facility consist of activated sludge with biological nutrient removal and tertiary treatment consisting of flow equalization, flocculation, sedimentation, and multimedia filtration.[2] This facility has a monthly average effluent limit of 50 g/L, which took effect in August, 2004. Only data collected after that effluent limit took effect have been analyzed (47 data points). Based on the 95th percentile of past performance, it appears that this facility could consistently comply with a concentration of about 34 g/L. In fact, after February 2005, this facility would never have violated an AML of 34 g/L.

Figure 9



[2] http://www.epa.gov/npdescan/CO0046507FS.pdf. Pages 3-4. Accessed 3/23/09.

Figure 10



Indian River County Utilities District (IRCUD) West Regional WWTF

The fact sheet describes this facility as an "advanced domestic wastewater treatment plant consisting of flow equalization, influent manual and mechanical bar screen, grit removal, anaerobic/anoxic tanks, aeration (an oxidation ditch), secondary clarifiers, chemical feed facilities, with dual filtration/chlorination trains, and aerobic digestion and rotary drum sludge thickening of residuals."[3]

One data point reported as 50 mg/L (50,000 g/L) was excluded without a statistical test. This data point is three orders of magnitude greater than the next largest value and is clearly an outlier. This value may have been reported using incorrect units (50 g/L, as opposed to mg/L, would be consistent with the plant's overall performance). After this data point was excluded, one additional data point was excluded based on a Grubb's extreme value test. Data collected prior to 2002 were statistically distinct from data collected and were also excluded.

The remaining data set consisted of 32 data points. Only three of these were greater than 30 g/L. Based on the 95th percentile of past performance, it appears that this facility could consistently achieve a concentration of about 60 g/L. However, if effluent variability were reduced, an even lower limit may be achievable by this facility.

[3] http://www.epa.gov/npdescan/FL0041637FS.pdf. Accessed 3/12/09. Page 1.

Figure 11

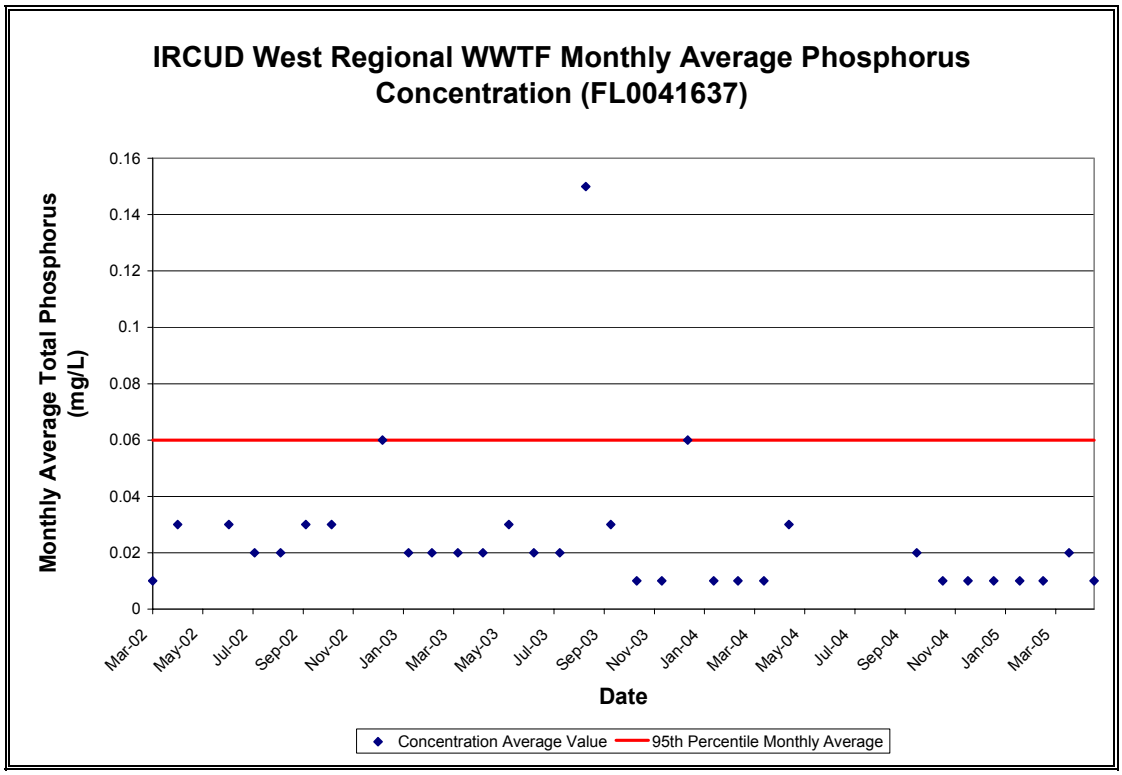
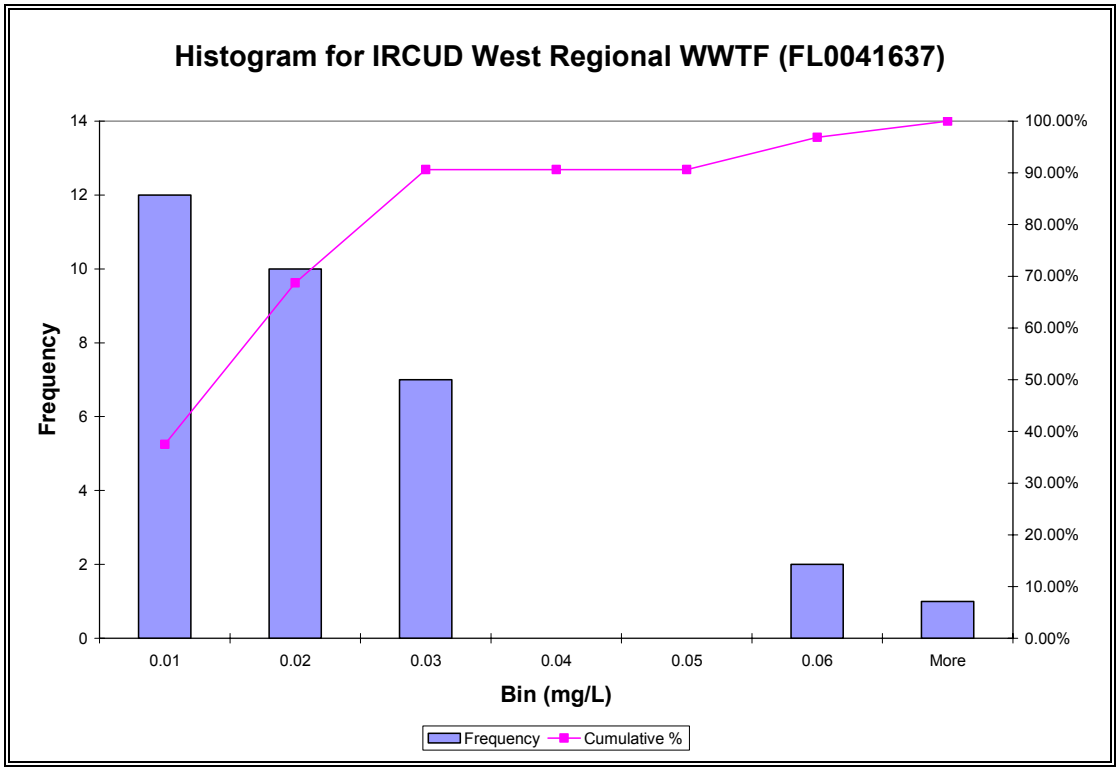


Figure 12



Stamford WWTP and Walton WWTP

The treatment processes for these facilities are described on Pages 34 and 39 of the 2007 EPA Region 10 AWT Report. A phosphorus effluent limit of 200 g/L took effect for these facilities in February 2003. Only effluent data collected after that time were considered. Most of the data for these facilities was reported as "less than" some value. As explained above, I have assumed that all of these values were equal to their "less than" thresholds, which will make these facilities' performance seem poorer than it actually is. After the "less than" substitution, one outlying data point was excluded from each of these facilities' data sets. The remaining data sets consisted of 40 data points for each facility.

Based on the 95th percentiles of past performance, it appears that these facilities could both consistently achieve a concentration of 22 to 23 g/L. This is consistent with previous reports (Table 6).

I performed a test with the Stamford effluent data, to determine the extent to which the treatment of "less than" data affected the 95th percentile and average values. The test consisted of substituting a value of zero for all of the "less than" data, instead of assuming that the actual values were equal to the "less than" values. This assumption would tend to make the effluent quality appear better than it actually is. I then recalculated the average and 95th percentile. This change reduced the average effluent concentration from 10 g/L to 5 g/L (which was expected), but it changed the 95th percentile concentration by only a fraction of a microgram per liter, from 22.4 g/L if I assume that the "less than" values are equal to the reporting thresholds, to 22.0 g/L if I assume the "less than" values are all equal to zero. All but three of the results for Walton facility were reported as "less than" some value. The substitutions performed likely affected the 95th percentile value for the Walton facility.

Figure 13

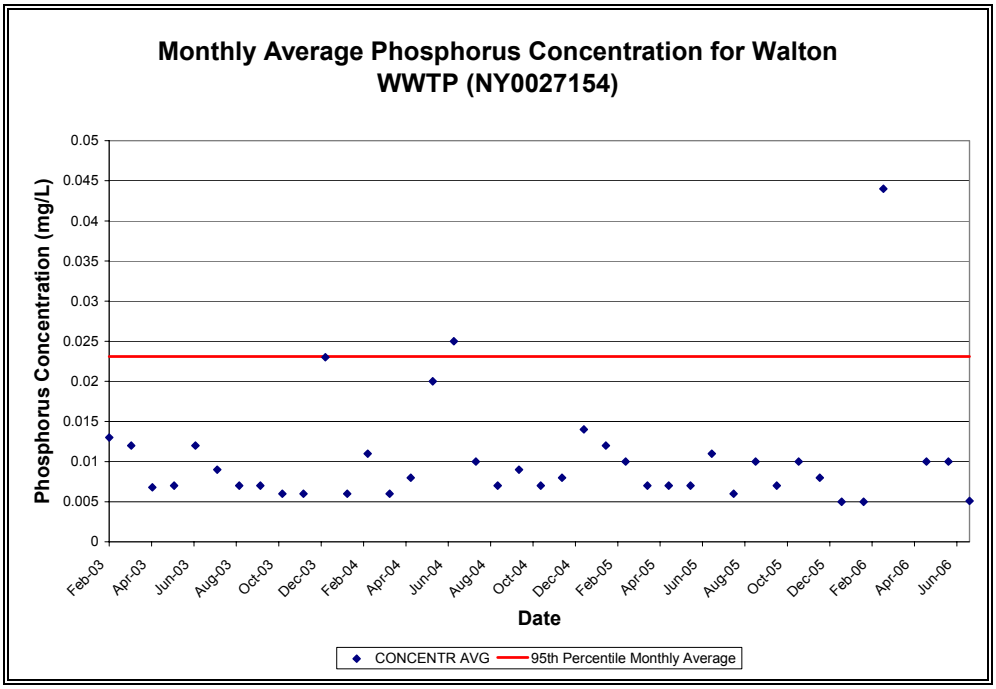


Figure 14

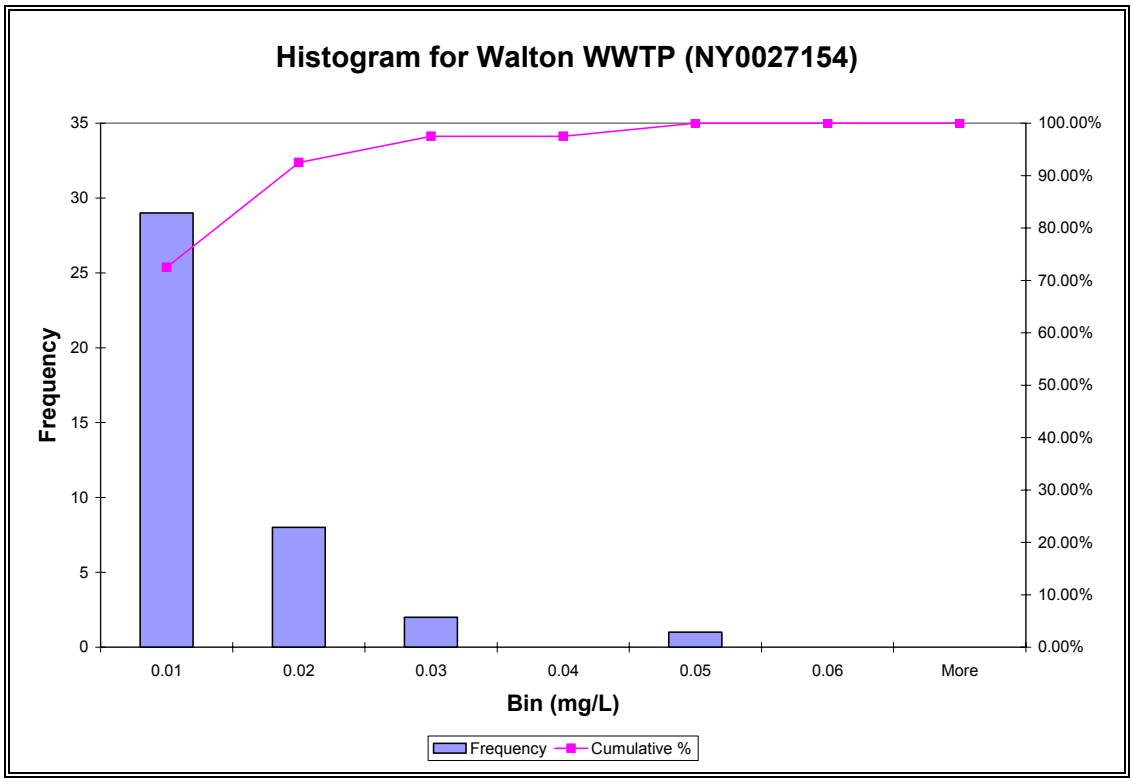


Figure 15

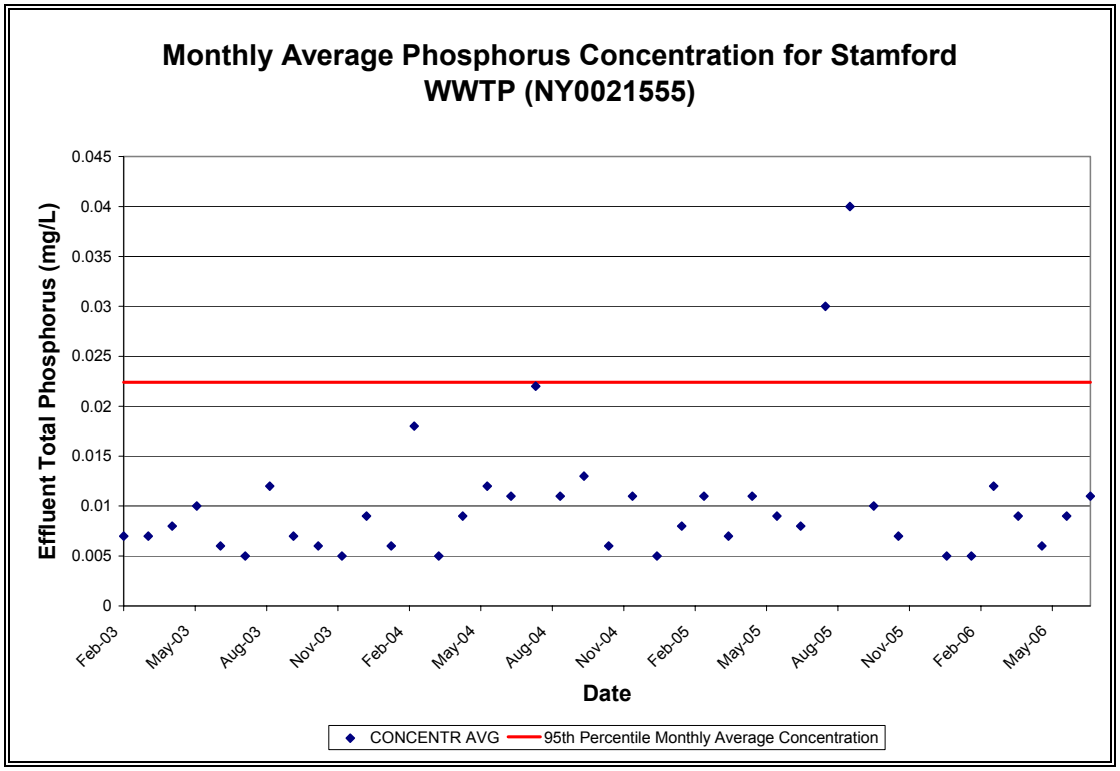
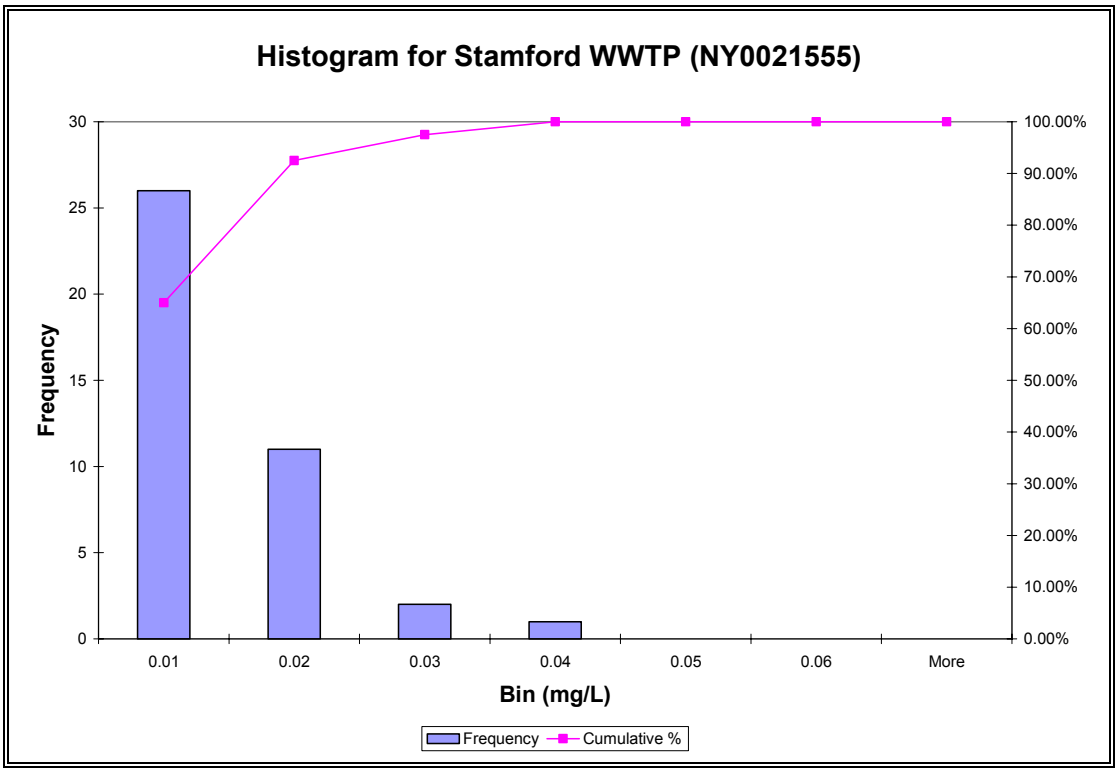


Figure 16



New York City DEP Grand Gorge STP

The treatment process for this facility is described on Page 8 of the 2007 EPA Region 10 AWT Report. An accurate quantification of this facility's performance is hampered by a data set that seems to reflect the use of insensitive analytical methods. Eight data points were reported as "less than" some value, and an additional 15 data points were reported as zero. The lowest nonzero value reported was 40 g/L; therefore, I substituted 40 g/L for the zero values. One outlying value (reported as <0.5 mg/L and assumed to be equal to 0.5 mg/L) was discarded based on a Grubb's extreme value test. The remaining data set consisted of 86 data points.

Based on the 95th percentile of past performance, it appears that this facility could consistently achieve a concentration of about 52 g/L, consistent with the Region 10 AWT report (Table 6).

Figure 17

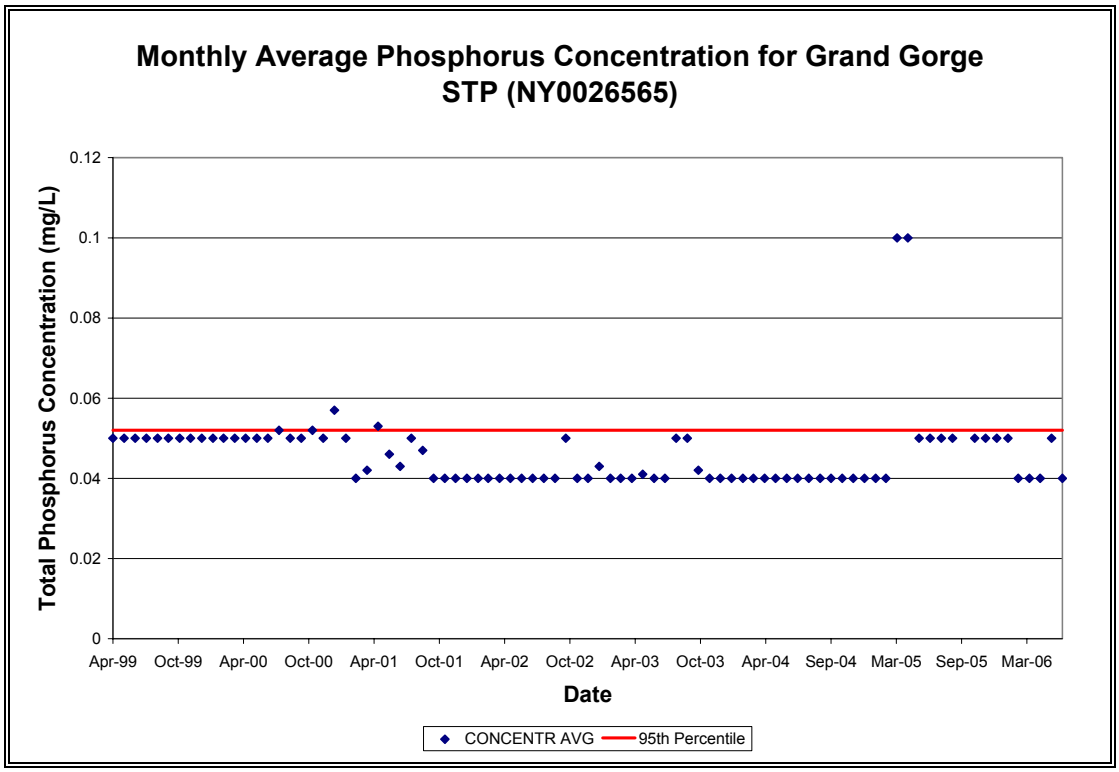
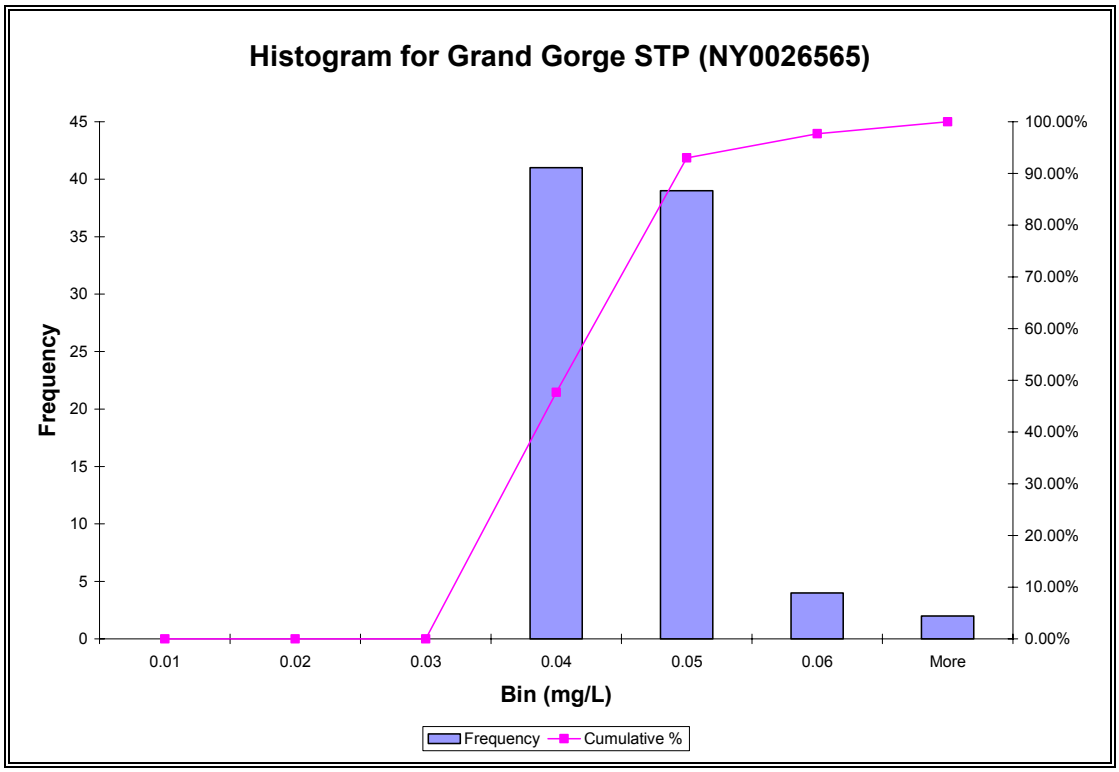


Figure 18

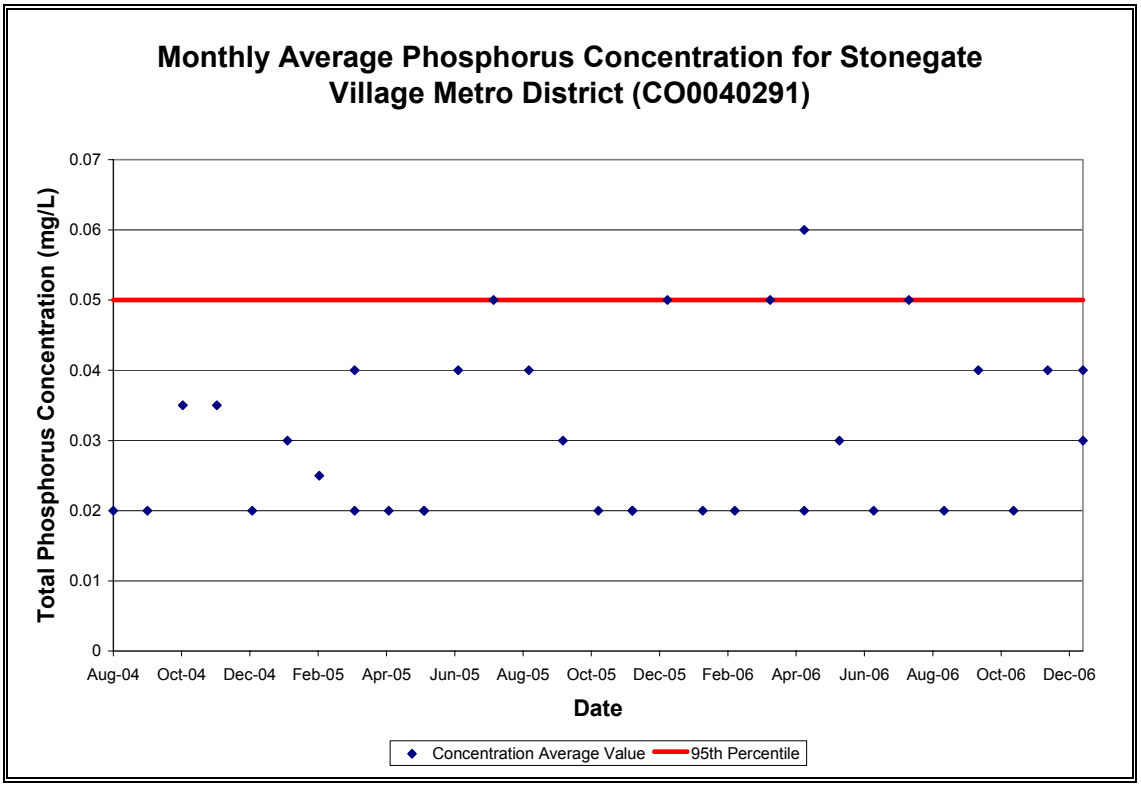


Stonegate Village Metro District WWTP

Treatment processes at this facility consist of extended aeration activated sludge, with tertiary treatment consisting of chemical addition (the alum dose is approximately 100 mg/L), tertiary clarification, and multimedia filtration.[4] This facility discharges from two outfalls: Outfall 001, described in the permit as "following treatment and prior to entering storage," and outfall 002, described as "following treatment and prior to mixing with the receiving stream." In August 2004, stringent phosphorus limits took effect for both outfalls (250 g/L for 001 and 50 g/L for 002). Only data collected after these effluent limits took effect were analyzed. There was no apparent difference in performance between these two outfalls, despite the different effluent limits and methods of disposal (storage versus discharge). However, for both outfalls, effluent data reported after January 1, 2007 were statistically distinct from data collected before that time (and after stringent limits took effect). The August 2004 – December 2006 period showed better performance than later data. Therefore, only the data (for both outfalls) from the August 2004 - December 2006 period when better performance was reported was further analyzed. Within that data set, 13 data points were reported as zero. The lowest nonzero value (20 g/L) was substituted for the zero values. The truncated data set contained 34 data points.

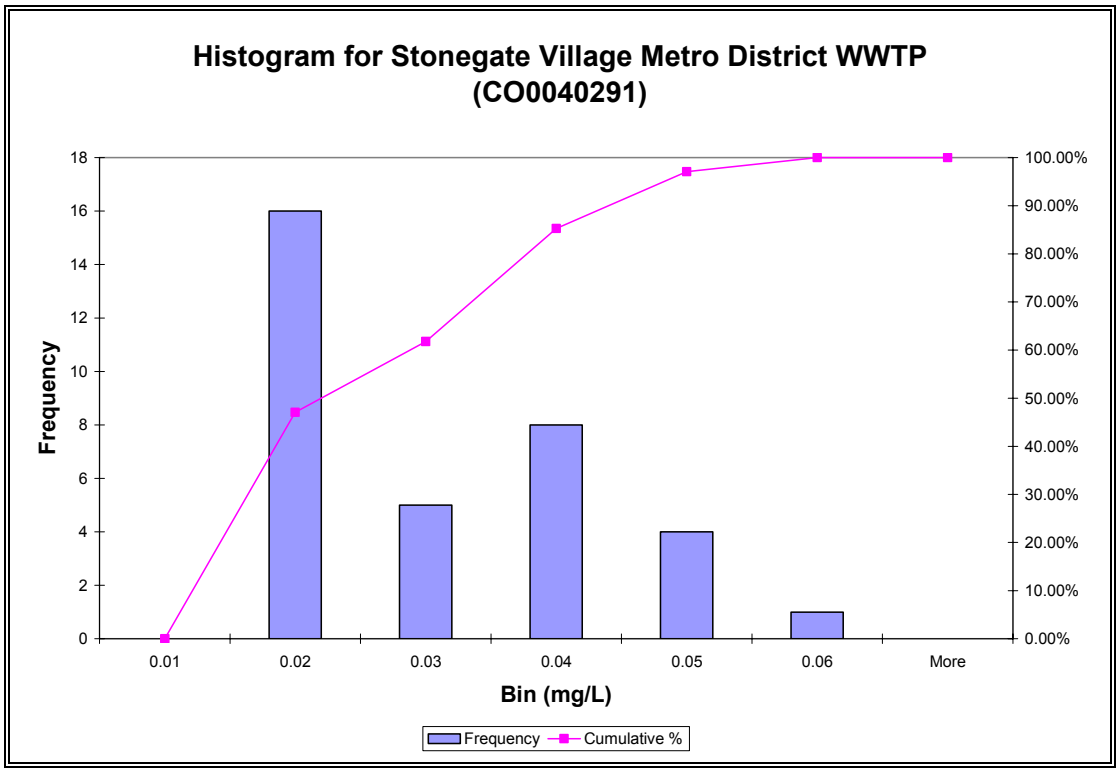
Based on the 95th percentile of past performance, it appears that this facility could consistently achieve an effluent concentration of about 50 g/L. This is somewhat poorer performance than that identified in previous reports (Table 6).

Figure 19



[4] http://www.epa.gov/npdescan/co0040291fs.pdf, Page 4, Accessed 3/23/09.

Figure 20



Combined Data for All Facilities

The data (with the above described exclusions and substitutions) for all facilities was combined into one spreadsheet and the same type of analysis was performed on this combined data set. The total sample size was 716 data points. The results are shown in Table 7 of the body of this memorandum. Figure 21, below, shows the combined data set as a histogram.