Evaluation of Sampling Variability in Chesapeake Bay Wastewater Treatment Plant Discharges

EPA Technical Memorandum

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Prepared by EPA Region III

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FIGURES

TABLES

ABBREVIATIONS

Mg/L .... Milligrams per Liter
MGD........ Million Gallons per Day
NPDES........National Pollutant Discharge Elimination System
TMDL........Total Maximum Daily Load
TN ....Total Nitrogen
TP........Total Phosphorus
EPA........ United States Environmental Protection Agency
WLA ....Waste Load Allocation
WWTP........Wastewater Treatment Plant

SCOPE

This technical memorandum addresses the load calculation methodology and sampling frequency of Chesapeake Bay watershed wastewater treatment plants (WWTPs) and identifies an approach that should result in data sufficient to support Chesapeake Bay jurisdictions'[1] trading and offset programs.

This technical memorandum assesses the post-treatment loads from two WWTPs to inform the recommendations. This technical memorandum assumes that sampling is random and that there is no bias created by drawing samples at non-representative modes of operation, such as sampling primarily when performance is good. The conclusions and recommendations account for the fact that samples can be drawn at non-representative points of time. The objectives of this assessment are to increase the accuracy of credit calculation for offsets and trading purposes by:

1. Determining if there are weekly, monthly or seasonal influences on the load calculations,
2. Assessing how differences in sampling frequency change the accuracy of the results,
3. Assessing the relationship among sampling frequency, accuracy of load estimates, and sampling cost, and
4. Assessing bias in average monthly loads using two different calculation methods.

This technical memorandum is not official agency guidance and does not replace the EPA 2003 Trading Policy.[2] Its purpose is to elaborate on EPA's expectations, set out in Appendix S and Section 10 of the 2010 Chesapeake Bay Total Maximum Daily Load (Bay TMDL),[3] for the Bay jurisdictions' offset and trading programs. As stated in the Bay TMDL, the Bay jurisdictions' offset and trading programs are expected to be consistent with and supportive of the water quality goals of the Bay TMDL, including its allocations and assumptions and the common elements of Appendix S. This technical memorandum is only applicable in the Chesapeake Bay watershed and may be revised in the future.

Offset and trading programs should be consistent with the Bay TMDL, the Clean Water Act[4] and its implementing regulations, EPA's 2003 Water Quality Trading Policy, and EPA's 2007 Water Quality Trading Toolkit for NPDES Permit Writers.[5]

INTRODUCTION

The load from WWTPs must be accurately measured in order to calculate the number of credits a WWTP needs to purchase or is able to sell. Chesapeake Bay TMDL wasteload allocations (WLAs) are required to be incorporated in NPDES permit effluent limits. Compliance with those permit limits typically is determined on an annual basis. The compliance period was justified based upon the physics and chemistry of the receiving water (Bay), recognition of the variability of waste streams as a result of climate and plant operation, and to give flexibility to WWTPs either through operation or through trading to meet their permit limits. Given the length of

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[1] The Chesapeake Bay jurisdictions are: Delaware, Maryland, Pennsylvania, New York, Virginia, West Virginia, and the District of Columbia.
[2] United States Environmental Protection Agency, "Water Quality Trading Policy, January 13, 2003." Available online at http://www.epa.gov/owow/watershed/trading/finalpolicy2003.pdf
[3] Text of the Chesapeake Bay TMDL: http://www.epa.gov/reg3wapd/tmdl/ChesapeakeBay/tmdlexec.html
[4] Clean Water Act, 33 U.S.C. §§ 1251 et seq.
[5] United States Environmental Protection Agency, "Water Quality Trading Toolkit for Permit Writers," Updated June 2009. Available online at http://water.epa.gov/type/watersheds/trading/WQTToolkit.cfm

the compliance period and the variability of the loads from the plant, it is necessary to establish a sampling frequency that captures the variability in load and therefore increases the accuracy of credit calculation.

The graphs below demonstrate that for the same monthly flow through a publicly-owned treatment plant (POTW) that serves a sanitary system, there can be orders of magnitude of variability in the monthly load. This could be the result of a number of causes: batch discharges into the sanitary system by industrial users, wet weather influences that dilute the influent and decrease treatment efficiency, or the variability of plant treatment efficiency due to deliberate or unintentional operation and maintenance practices. These causes are sporadic and the sampling frequency should be sufficient to capture these incidences if loads are to be estimated accurately.

The high variability in loads from some WWTPs in the Chesapeake Bay watershed illustrates the need to assess the error associated with different sampling frequencies and calculations methodologies. The figures of total nitrogen (TN) and total phosphorus (TP) loads from three WWTPs in the Chesapeake Bay watershed depicted below from an earlier data review illustrate this variability.

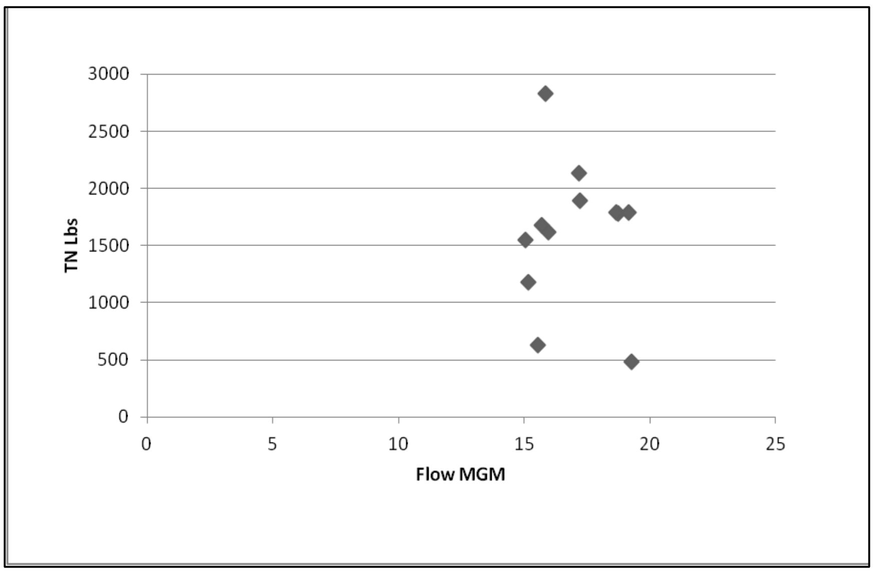


Figure : Total nitrogen loads from a WWTP with an annual limit of 9,471 and actual discharge of 19,347. Average monthly flow ranged from 15.035 to 19.29. Discharges exceeded annual limits 214 days.

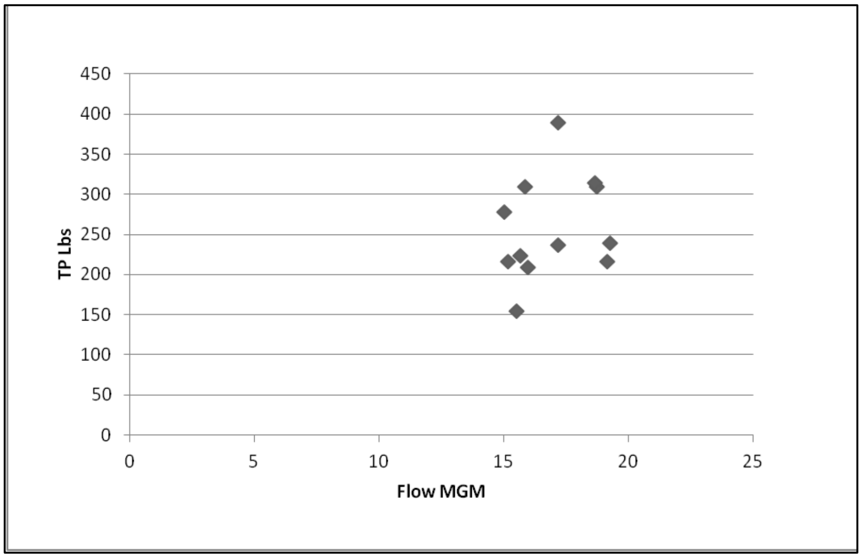


Figure : Total phosphorus loads from a WWTP with an annual limit of 1,218 and actual discharge of 3,104. Average monthly flow ranged from 15.035 to 19.29. Discharges exceeded annual limits 242 days.

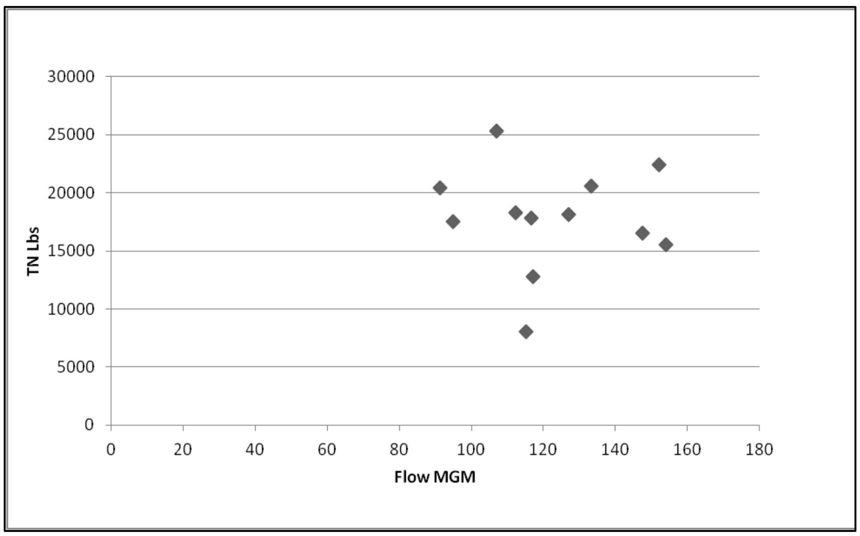


Figure : Total nitrogen loads from a WWTP with an annual limit of 109,588 and actual discharge of 213,471. Average monthly flow ranged from 91.35 to 153.92. Discharges exceeded annual limits 214 days.

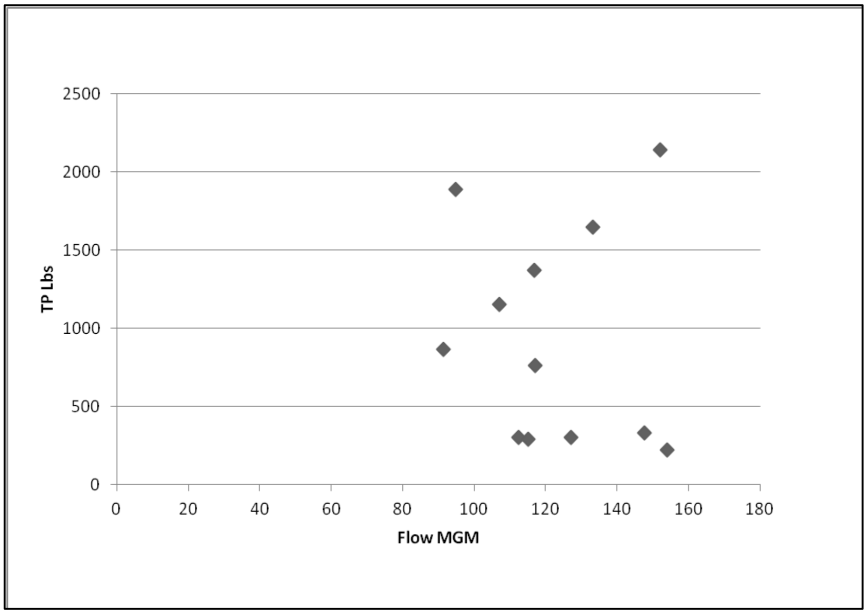


Figure : Total phosphorus loads from a WWTP with an annual limit of 14,612 and actual discharge of 9,908. Average monthly flow ranged from 91.35 to 153.92.

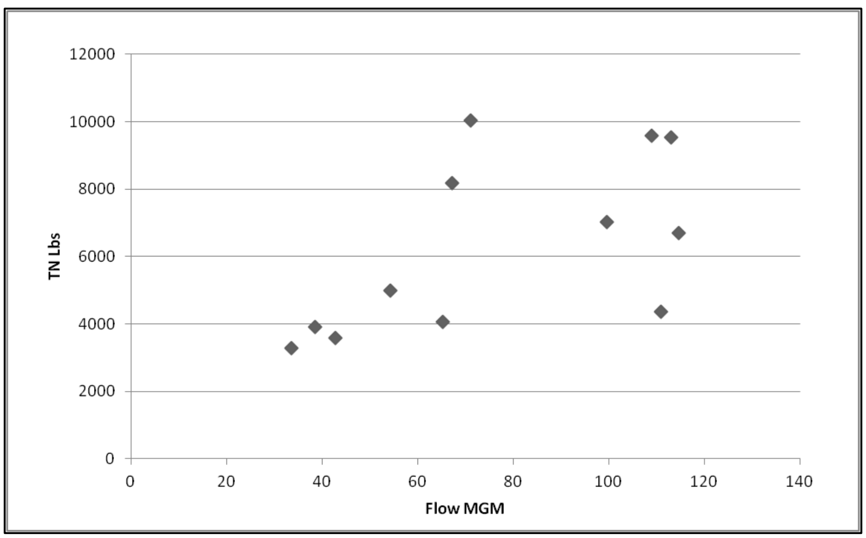


Figure : Total nitrogen loads from a WWTP with an annual limit of 44,200 and actual discharge of 75,196. Average monthly flow ranged from 33.697 to 114.7. Discharges exceeded annual limits 154 days.

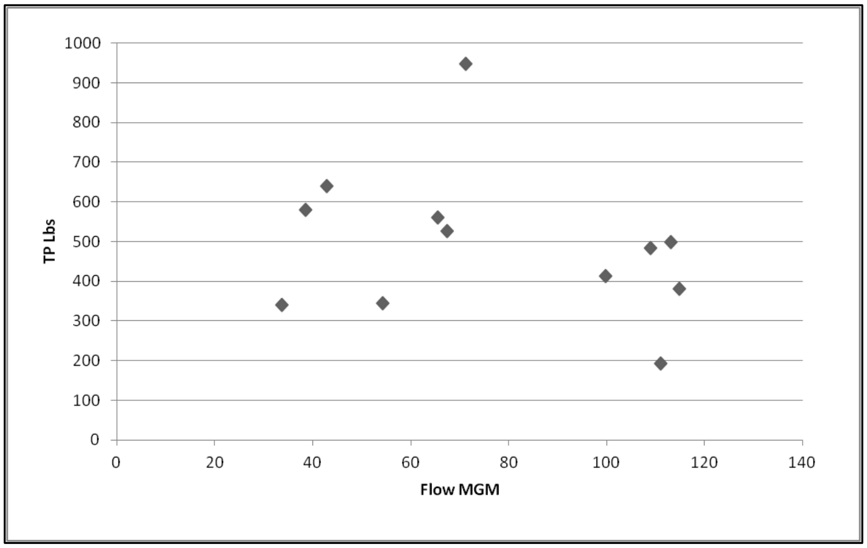


Figure : Total phosphorus loads from a WWTP with an annual limit of 5,893 and actual discharge of 5,907. Average monthly flow ranged from 33.697 to 114.7. Discharges exceeded annual limits 30 days.

Given this variability and the need to accurately sample and calculate loads for offsets and trading, an assessment of sampling frequency and calculation methodology was undertaken. Monitoring and sampling data regarding the discharge of total nitrogen and total phosphorus loads from two individual significant point sources are used to assess compliance with the water quality based effluent limits in NPDES permits, which federal regulations require to be consistent with the assumptions and requirements of any applicable wasteload allocations (WLAs), which includes those in the Bay TMDL. The Bay TMDL Section 10 and Appendix S contain provisions describing EPA's expectation that any new or increased loads will be offset through acceptable offsets. Some Bay jurisdictions are also trading nutrient credits for compliance with NPDES effluent limits. As discussed below, the method for sampling and calculating the loads affects the determination of the overall nutrient load discharged to the Chesapeake Bay and also affects the accuracy of credit calculation. EPA chose to examine sampling and calculation methods in Virginia and Pennsylvania and selected one facility in each, providing for some diversity within the Chesapeake Bay Watershed. Daily monitoring data, which was required to perform the analysis in this technical memorandum, was available for each of these facilities. The analysis of these two facilities' discharges informs the recommendations in this technical memorandum.

WWTPs are point sources that report TN and TP based on load estimates generated from limited sampling of plant discharges into streams and rivers. WWTPs in the Chesapeake Bay watershed sample at a frequency that depends on the flow discharged, and report TN and TP discharges as monthly averages of those samples. For example, current regulations in Virginia require two composite samples per month for small discharges, one per week for flows between 1 and 20 million gallons per day (MGD), and three samples for flows above 20 MGD. Pennsylvania currently requires one sample per week for all flows.

The current calculation methodology for TN and TP samples in Virginia and Pennsylvania uses the sum of the concentration of measured nitrogen or phosphorus species in milligrams per liter, and then multiplies that concentration by the 24-hour flow rate to produce a load for that day. The loads for the month (one per week resulting in a total of four, for example) are used to calculate an average daily load result. That average daily load figure is multiplied by the number of days in the month to produce the monthly load.

The sampling frequency and calculation method may introduce error into the load calculations when there are weekly, monthly or seasonal variations in actual TN and TP discharges that are not measured in the samples drawn during each week. Error also can be introduced when sampling occurs at non-representative conditions, such as sampling primarily when performance is good. WWTPs are among the most likely future buyers of nutrient credits to meet their effluent limits. In addition, accurate load calculations for TN and TP discharges from WWTPs are critical to assure that any new or increased load is offset to prevent an increase in pollutant load in the Chesapeake Bay.

The Virginia Department of Environmental Quality (VDEQ) has daily TN and TP data for the Alexandria ASA Advanced WWTP. Pennsylvania Department of Environmental Protection (PaDEP) has daily TP and weekly TN data for the Harrisburg City, Dauphin County WWTP. These data are sufficient to estimate the potential error introduced into TN and TP total load calculations from using only one or two samples of plant discharge per week that are subsequently aggregated to monthly estimates. The data from the two facilities also allow for a quantitative assessment of the cost effectiveness of increasing the number of samples per week in terms of improvement in the total TN and TP load calculations. Finally, the data from the two facilities enable a comparison of two alternative methods for calculating total loads.

STUDY DESIGN AND METHODS

The following sections discuss the sources of data and the analytical methods used. The analytical methods section provides a detailed account of the procedure that was followed in completing the analyses discussed in the results section. These analyses assume that sampling was random and samples were not drawn at non-representative modes of operation.

DATA SOURCES

Daily monitoring data was required to determine if less than daily sampling resulted in different loads. As such, data was acquired from two plants that monitor daily. VDEQ provided daily monitoring data from the Alexandria ASA Advanced WWTP from 2009 and 2010, including TN, TP, and flow rate for 365 days for the two years. PaDEP provided daily sampling data for the Harrisburg City, Dauphin County WWTP for 2010, including daily TP, weekly TN, and daily flow rate for 365 days. The Harrisburg WWTP provided the original paper lab records for each sample taken in 2010. These data were entered into a spreadsheet and a ten percent quality control check was performed on the data entry. These two WWTPs are large plants with high loads and flows, which is why they are already sampling on a daily basis.

Laboratory costs for measuring TN and TP in wastewater discharge samples were acquired by requesting lab fee schedules from two labs that serve the Mid-Atlantic area. The lab cost per sample for measuring total dissolved solids, total Kjeldahl nitrogen, nitrite (NO_2), nitrate (NO_3), and total phosphorus was $80 from A&L Eastern Lab and $70 from Microbac Laboratories. The estimates reported below use an average cost of $75 to compare increased cost with decreased error associated with additional sampling. These costs are assumed to be the only relevant costs associated with increased sampling of discharge from the facilities.

ANALYTICAL METHODS

The monthly average loads from all facilities were examined to determine if there is a seasonal influence on monthly average loads using plots of TN or TP plotted against the sample month in SAS 9.3 (SAS Institute Inc., 2010). While time series methods were considered, such methods were deemed not feasible with only one or two years of data available.

Sampling frequencies of 1, 2, 3, 5, and 7 samples per week were compared to determine the confidence intervals of various sampling frequencies. Data were compared as an average daily value since there was no pattern of seasonality across daily samples for the Alexandria ASA Advanced WWTP for 2009 and 2010 TN and 2010 TP or for the Harrisburg Plant for TN or TP. The daily monitoring data from 2009 and 2010 for the Alexandria ASA Advanced WWTP and 2010 for the Harrisburg WWTP were assessed to determine if any one day of the week was statistically different from another. The Z-score was used to compare the standard deviations of the means of the days that were the highest and lowest. For the Alexandria ASA Advanced WWTP, the day of the week was used for subsampling the number of days. For the Harrisburg WWTP, the days were assigned a random number for subsampling the number of days (

Table). The percent difference among the various sampling frequencies was calculated along with confidence intervals. The difference among daily samples was related to costs to determine the impact of increased sampling on cost.

Table : Days of the week that were subsampled to compare to daily sampling

Number of days per week	Day of the week used to represent sample days (Alexandria data)	Random number used to represent sample days (Harrisburg data)
1	Monday	1
2	Monday and Wednesday	1 and 2
3	Monday, Wednesday, Friday	1 through 3
5	Monday through Friday	1 through 5
7	Monday through Sunday	1 through 7

Two methods for calculating the monthly average load were compared. Samples of concentration and flow were used to calculate a load. The load was calculated for each sampling day. The calculated loads were averaged for the month. An alternative method for determining the average monthly load was used where the average of the concentration and the average of the flow were calculated for all samples in the month, prior to calculating the load. The percent difference was compared to determine if the data are biased in any one direction.

RESULTS OF THE ALEXANDRIA ASA ADVANCED WWTP

TEMPORAL DISCHARGE PATTERNS

The distribution of samples for 2010 from the Alexandria ASA Advanced WWTP was assessed to determine if any temporal pattern influenced load results. Seasonality of discharges was determined by plotting the average monthly load of TN (pounds) or TP (pounds) against the sampling month for January 2009 to December 2010. There were elevated values for TN in April 2009, November 2009, December 2009, February 2010, March 2010, and April 2010 (Figure). There were elevated values for TP in June 2009, July 2009, October

2009, March 2010 and October 2010 (Figure). Due to the level of variability shown below, these do not appear to reflect a strong seasonal pattern.

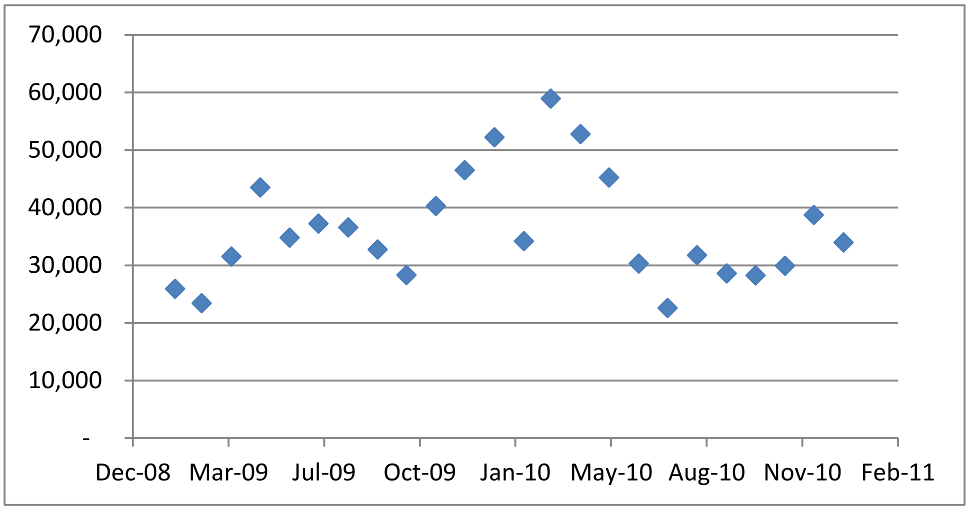


Figure : Plot of monthly average TN (pounds) for January 2009 to December 2010 for the Alexandria ASA Advanced WWTP.

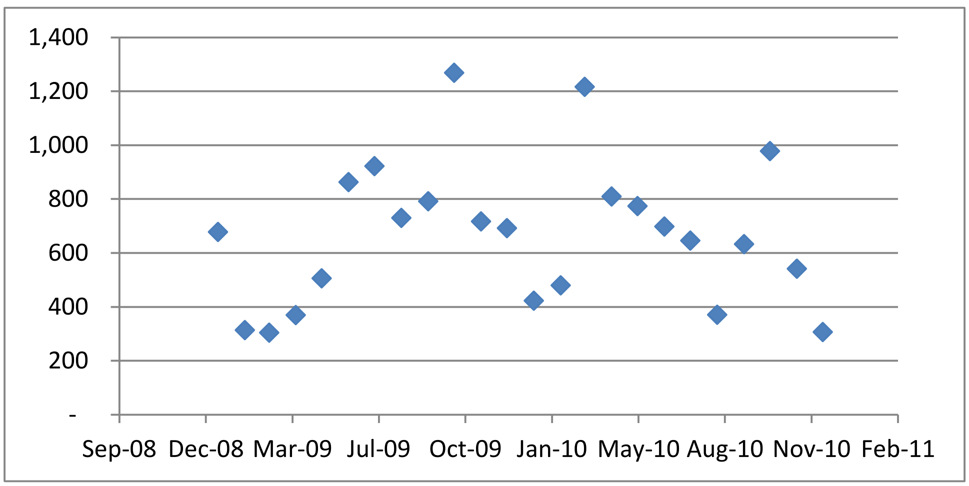


Figure : Plot of monthly average TP (pounds) for January 2009 to December 2010 for the Alexandria ASA Advanced WWTP.

IMPACT OF INCREASED SAMPLING ON LOAD CALCULATIONS

The daily data from Alexandria ASA Advanced WWTP was used to assess the impact of increasing the number of sampling days per week on the accuracy of monthly load calculations. To do this, loads were calculated from the Alexandria ASA Advanced WWTP data by varying the source data from one to seven days per week. The analysis was conducted for both 2009 and 2010. The specific days of data that were used in the calculations are in

Table above.

To determine if any one day of the week was different than another, a Z-test was used to compare between the days with the highest and lowest mean value for load (Table). The Z-score indicates how many standard deviations from the mean the value is. A score of ±1.64, or one standard deviation, is considered significant. For 2010, the highest mean was for Wednesdays (TN=1,244; TP=19) and the lowest mean was for Fridays (TN=1,237; TP=22). For 2009, the highest mean was for Saturdays (TN=1,233; TP=27) and the lowest mean was for Tuesdays (TN=1,113; TP=19).The means are not significantly different for TN for 2009, TN 2010, and TP for 2010. There is a statistically-significant difference for TP for 2009.

Table : Z-scores for comparison of highest and lowest mean among the day of the week sample for the Alexandria ASA Advanced WWTP. This assessed if there was bias among days of the week.

Year	Days Compared	Z-Score for TN	Z-Score for TP
2009	Saturdays and Tuesdays	1.13	2.46
2010	Wednesdays and Fridays	-0.07	1.00

The load is calculated for each day of sampling using the formula below. The load from each day of sampling is then averaged for the month. (Note: An alternative method is examined in a following section, below.)

Load (pounds) = Flow (MGD) * Concentration (mg/L) * Conversion factor (8.344)[6]

The conversion factor is used to convert the units from million gallons per day (MGD) to milligrams per liter (mg/L). Confidence intervals were calculated for each of the number of sampling days (Table). The data indicate the following:

1. As the number of sampling days increases, the load estimate converges to the seven-day value and the confidence intervals shrink. There is measurable change in the estimate every time a new day of sampling is added (Figure , and Figure).
2. The greatest change in the load estimate occurs when the number of sampling days increases from 1 to 2 days.
3. Less than 5% error is achieved for both TN and TP if sampling occurs three times a week or more.

Table : Confidence limits and mean loads given different number of days per week of sampling for Alexandria ASA Advanced WWTP.

Year	Variable	Parameter	Estimate	Lower Confidence Limit	Upper Confidence Limit	Percent Error Compared to Daily Sampling	Days of Sampling
2010	TN	Mean	1,045.48	919.01	1,171.95	-12%	1
2010	TN	Mean	1,144.67	1,054.51	1,234.84	-4%	2
2010	TN	Mean	1,175.91	1,101.95	1,249.87	-1%	3

[6] Note that the conversion factor used in the analyses in this report is 8.344, which is consistent with the factor used by the Chesapeake Bay Program. Virginia uses the 8.345 factor under the current general permit The 8.345 factor is recommended by the American Society of Civil Engineers and is commonly used in EPA calculations for average daily load.

Year	Variable	Parameter	Estimate	Lower Confidence Limit	Upper Confidence Limit	Percent Error Compared to Daily Sampling	Days of Sampling
2010	TN	Mean	1,194.34	1,135.50	1,253.18	0%	5
2010	TN	Mean	1,192.24	1,139.88	1,244.60	0%	7
2010	TP	Mean	22.52	17.43	27.61	4%	1
2010	TP	Mean	20.88	18.01	23.74	-3%	2
2010	TP	Mean	21.15	18.83	23.46	-2%	3
2010	TP	Mean	20.96	19.25	22.67	-3%	5
2010	TP	Mean	21.59	20.11	23.06	0%	7
2009	TN	Mean	909.98	817.98	1,001.99	-23%	1
2009	TN	Mean	1,161.84	1,050.79	1,272.89	-2%	2
2009	TN	Mean	1,203.48	1,119.62	1,287.34	1%	3
2009	TN	Mean	1,214.22	1,152.82	1,275.62	2%	5
2009	TN	Mean	1,186.53	1,132.50	1,240.55	0%	7
2009	TP	Mean	20.12	17.63	22.60	-10%	1
2009	TP	Mean	20.82	18.47	23.16	-7%	2
2009	TP	Mean	21.73	19.73	23.73	-3%	3
2009	TP	Mean	21.37	19.79	22.95	-4%	5
2009	TP	Mean	22.36	20.89	23.83	0%	7

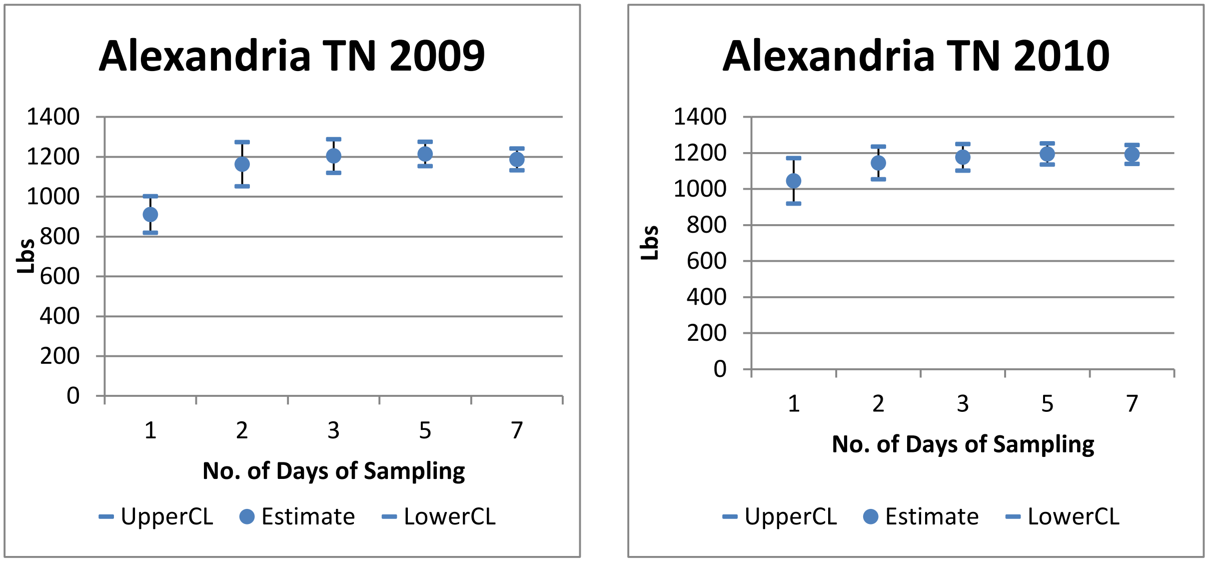


Figure : Confidence limits for the estimated TN load in 2009 and 2010 given different number of samples per week.

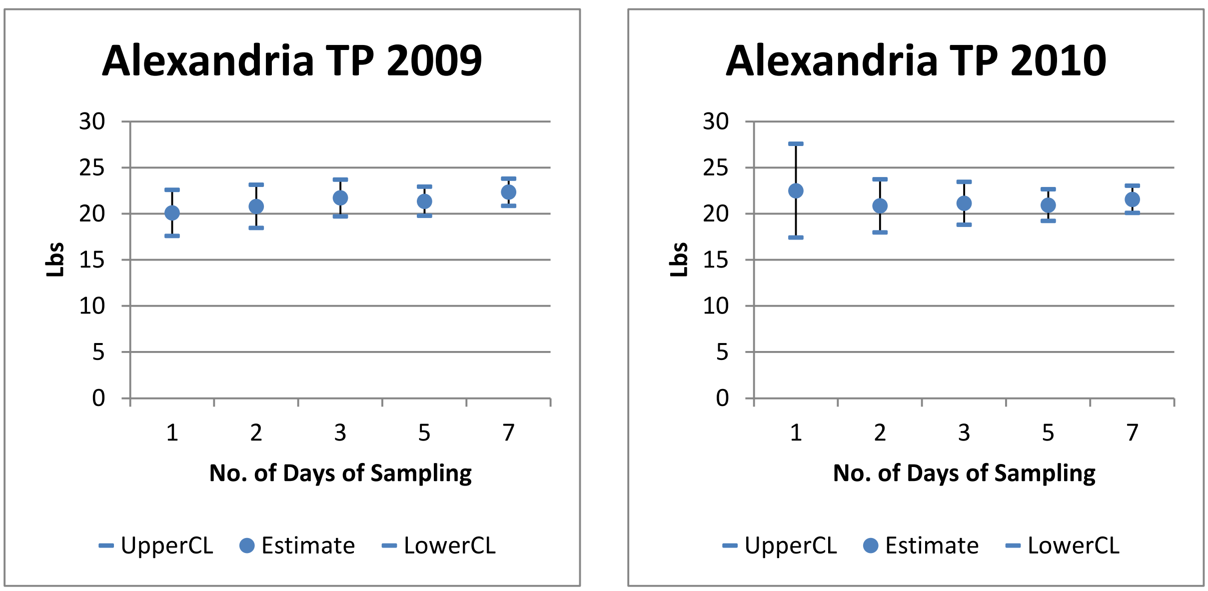


Figure : Confidence limits for the estimated TP load in 2009 and 2010 given different number of samples per week.

COST EFFECTIVENESS OF INCREASED SAMPLING

The costs associated with increased days of sampling were determined by plotting the percent deviation from the daily sampling mean for sampling one, two, three, or five times a week. Costs increase relative to sampling frequency while there is a concurrent decrease in error for increasing the number of days of sampling (Figure , Figure , Figure , and Figure).

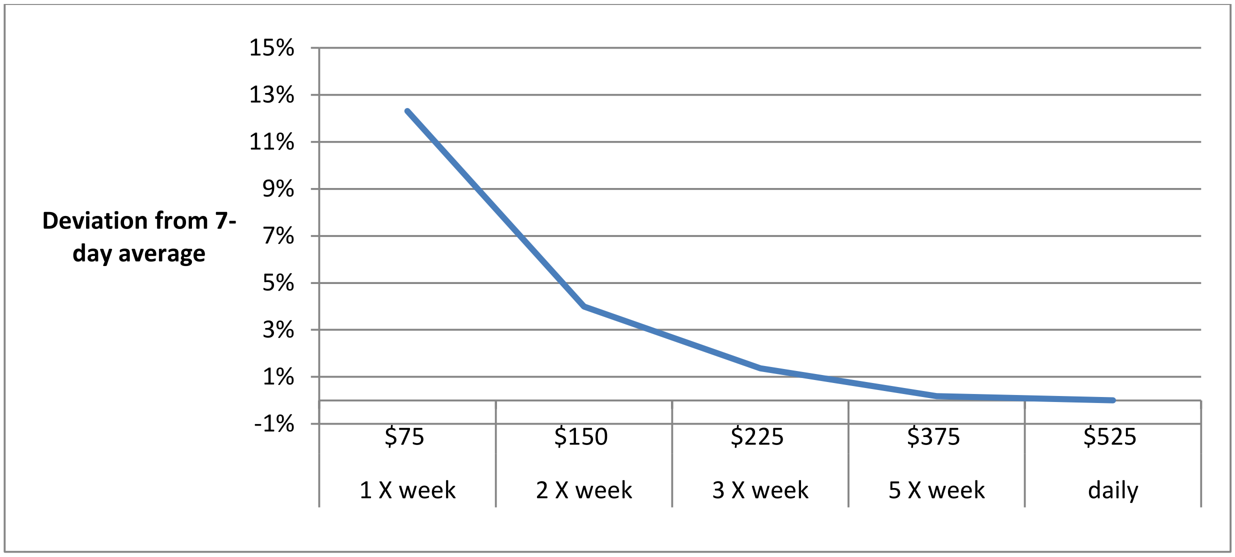


Figure : Increases in cost associated with decreases in error for different number of days of sampling at the Alexandria ASA Advanced WWTP in 2010 for TN.

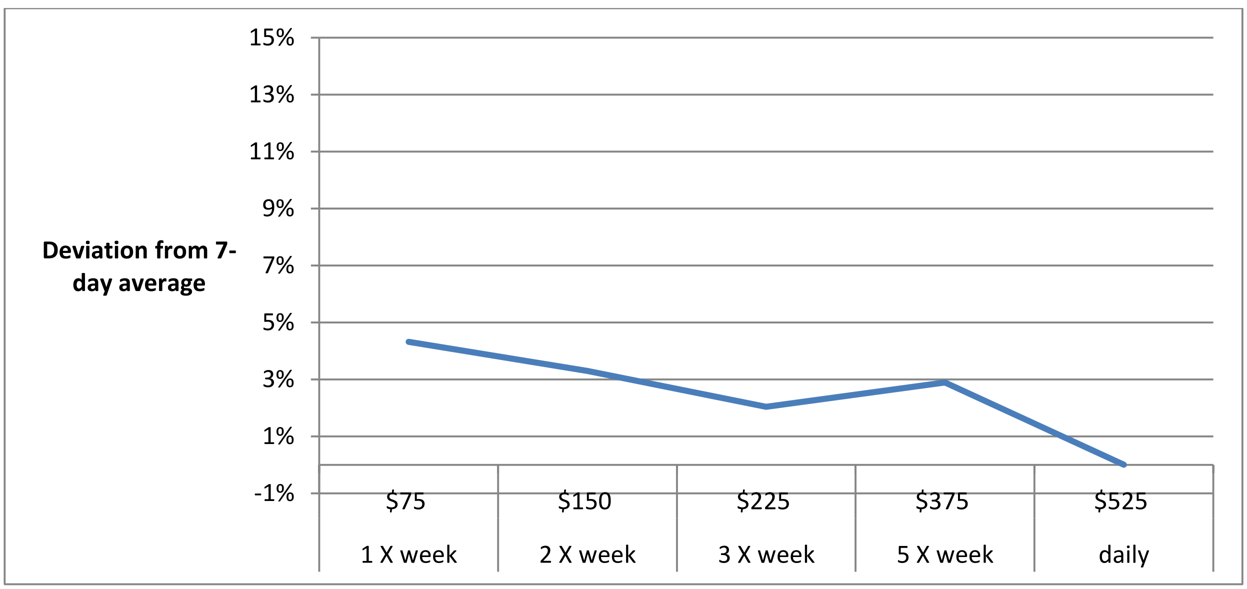


Figure : Increases in cost associated with decreases in error for different number of days of sampling at the Alexandria ASA Advanced WWTP in 2010 for TP.

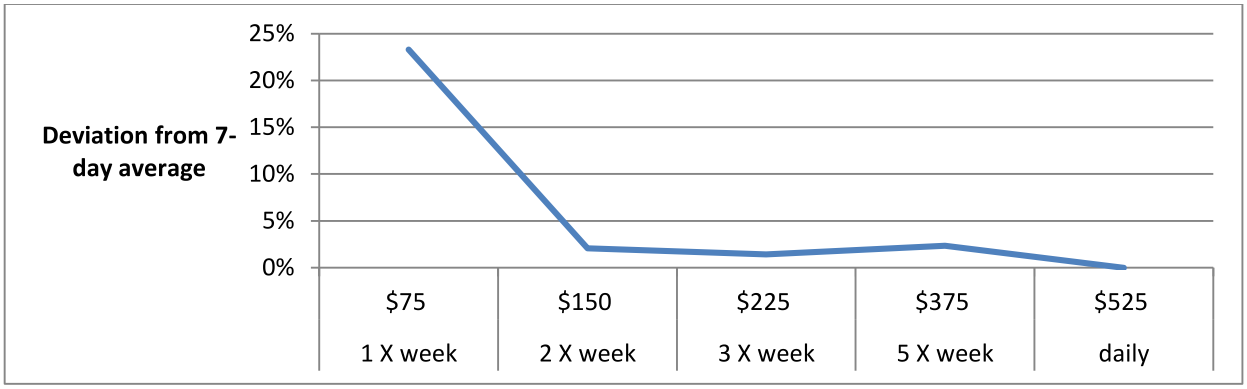


Figure : Increases in cost associated with decreases in error for different number of days of sampling at the Alexandria ASA Advanced WWTP in 2009 for TN.

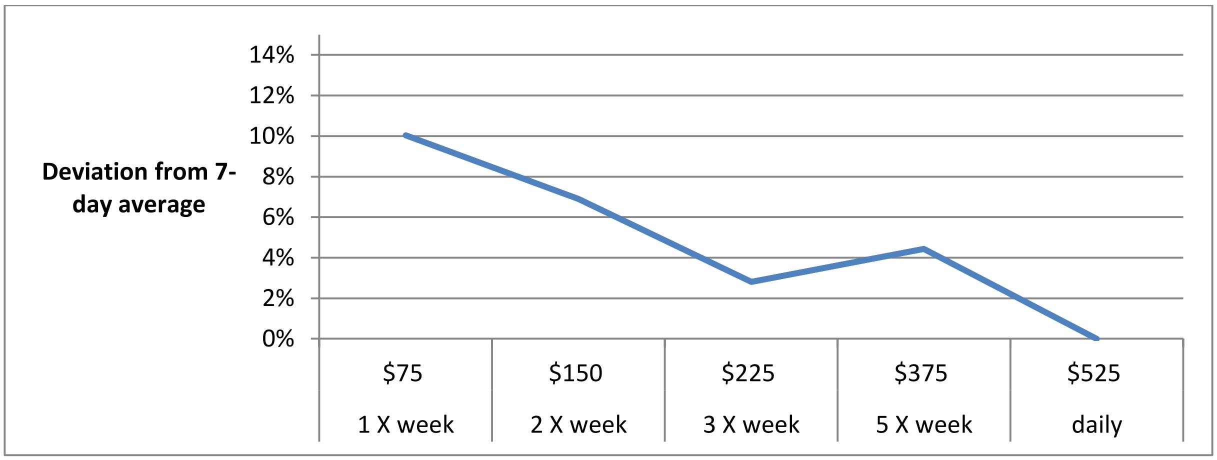
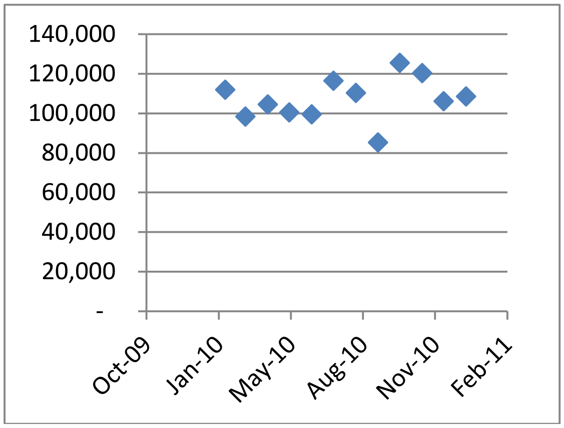


Figure : Increases in cost associated with decreases in error for different number of days of sampling at the Alexandria ASA Advanced WWTP in 2009 for TP.

RESULTS OF THE HARRISBURG WWTP

TEMPORAL DISCHARGE PATTERNS

The distribution of temporal patterns from the Harrisburg WWTP in 2010 was assessed to determine if any such temporal pattern influenced load results. Seasonality of discharges was determined by plotting the average monthly loads TN (pounds) or TP (pounds) against the sampling month for 2010. There were elevated values for TN in September and October. These do not appear to reflect a seasonal pattern. TP was higher in the first six months of the year than in the last six months of the year. Within those first six months, TP was elevated in January and April (Figure).



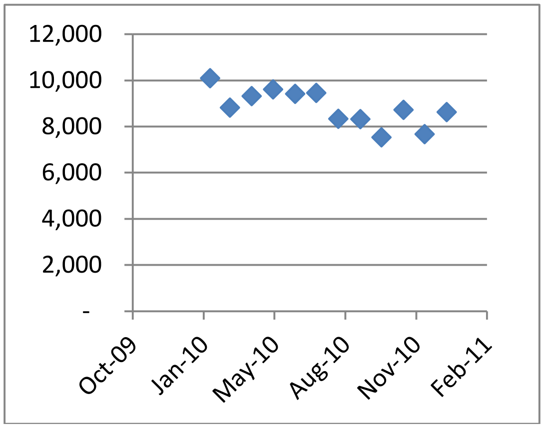


Figure : Plot of monthly average pounds of TN (left) and TP (right) by monitoring date for Harrisburg WWTP for calendar year 2010.

IMPACT OF INCREASED SAMPLING ON LOAD CALCULATIONS

The TP daily data from Harrisburg WWTP was used to assess the impact of increasing the number of sampling days per week on the accuracy of monthly load calculations. To do this, loads were calculated from the Harrisburg data by varying the source data from one to seven days per week. This analysis was performed solely for TP, since the TN data was consistently sampled once a week.

To determine if any one day of the week was different than another, a Z-test was used to compare between the days with the highest and lowest mean value for load (Table). The Z-score indicates how many standard deviations from the mean the value is. A score of ±1.64, or one standard deviation, is considered significant. For 2010, the highest mean was for Thursdays (TP=306) and the lowest mean was for Saturdays (TP=271). The means are significantly different for TP with a Z-score = 2.55. Therefore subsampling the number of samples per week using day of the week is invalid since there are differences in concentrations among days of the week.

A random number between one and seven was assigned to each day of the year. These were distributed equally so that no number was represented more frequently than another. That is, there were 52 instances of numbers two through seven and 53 instances of the number one. The Z score was then calculated based on the random number assignment. The days assigned as two had the lowest mean (TP=286) and the days assigned the number three had the highest mean (TP=297.92). The Z-score was 0.87. No one number from one to seven is significantly different than another.

The load is calculated for each day of sampling using the formula below. The load from each day of sampling is then averaged for the month. (Note: An alternative method is examined in a following section on , below.)

Load (pounds) = Flow (MGD) * Concentration (mg/L) * Conversion factor (8.344)[7]

[7] Note that the conversion factor used in the analyses in this report is 8.344, which is consistent with the factor used by the Chesapeake Bay Program. Virginia uses 8.345 under the current general permit. Maryland uses 8.34.

The conversion factor is used to convert the units from million gallons per day (MGD) to milligrams per liter (mg/L). Confidence intervals were calculated for each of the number of sampling days (Table). The data indicate the following:

1. As the number of sampling days increases, the load estimate converges to the seven-day value and the confidence intervals shrink. There is measurable change in the estimate every time a new day of sampling is added (Figure).
2. The greatest change in the load estimate occurs when the number of sampling days increases from 1 to 2 days.
3. Less than 3% error is achieved if sampling occurs once weekly. This drops to 1% error if sampling occurs two times weekly.

Table : Confidence limits and mean loads given different number of days of sampling for the Harrisburg 2010 WWTP.

Year	Variable	Parameter	Estimate	Lower Confidence Limit	Upper Confidence Limit	Percent Error Compared to Daily Sampling	Days of Sampling
2010	TP	Mean	298.82	281.67	315.97	3%	1
2010	TP	Mean	292.37	279.178	305.56	1%	2
2010	TP	Mean	294.21	283.50	304.92	1%	3
2010	TP	Mean	290.68	282.00	299.37	0%	5
2010	TP	Mean	290.23	282.96	297.50	0%	7

The 8.345 factor is recommended by the American Society of Civil Engineers and is commonly used in EPA calculations for average daily load.

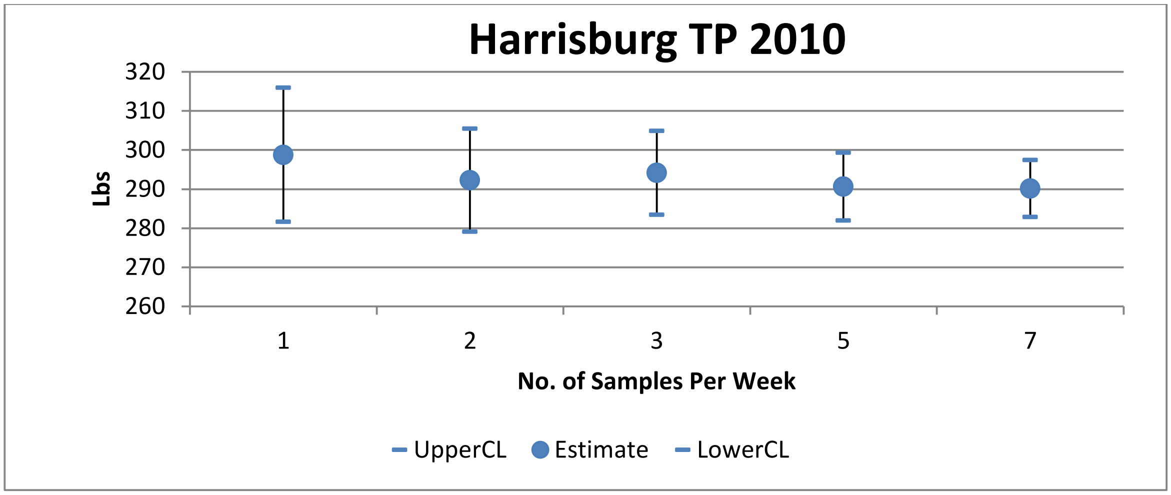


Figure : Confidence limits around the estimated TP load for 2010 given different number of samples per week.

COST EFFECTIVENESS OF INCREASED SAMPLING

The costs associated with increased days of sampling were determined by plotting the percent deviation from the daily sampling mean for sampling one, two, three or five times a week. There is no deviation for seven times a week because seven days a week was the baseline for calculation the deviation. This analysis was for the Harrisburg WWTP in 2010 for TP. Costs increase relative to sampling frequency while there is a concurrent decrease in error for one and two times a week (Figure).

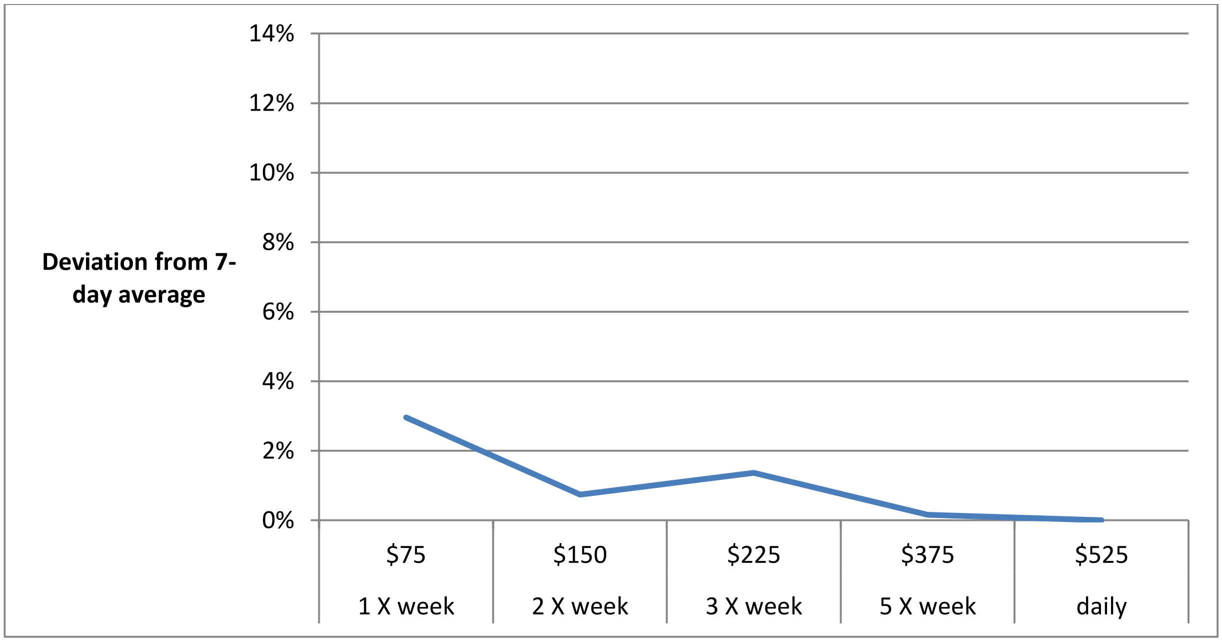


Figure : Increase in cost associated with decrease in error for different number of days of sampling at the Harrisburg WWTP in 2010 for TP.

COMPARISON OF METHODS FOR CALCULATING THE AVERAGE MONTHLY LOAD FOR BOTH THE HARRISBURG AND ALEXANDRIA ASA ADVANCED WWTPS

The current sampling methodology for TN uses the sum of the concentration of nitrogen species in mg/L then multiplies that concentration by the 24-hour flow and a conversion factor to produce a load for that day. The loads for the month (one per week resulting in a total of four, for example) are then used to calculate an average daily load. That average daily load is then multiplied by the number of days in the month to produce the monthly load. The same method is used for TP.

Current method:

1. Daily load=concentration * flow * 8.344[8]
2. Average monthly load = average of all calculated loads in a month * no. of days in a month

A proposed alternative method is to calculate the load after the concentration and flow are averaged for the month.

1. Average concentration for samples in a month
2. Average daily flow
3. Average Monthly Load = average concentration * average daily flow * 8.344 * no. of days in month

The data from the Alexandria ASA Advanced and Harrisburg WWTPs have similar results. Both show that the current method is slightly biased toward higher load estimates than the alternative method (Table , Table , Figure , and Figure). For the Alexandria ASA Advanced WWTP, TN and TP trend together but a greater difference is apparent for TN than for TP primarily because the loads are higher for TN. For both plants, the month that shows the greatest difference is September. The September 30, 2010 sample had more than double the amount of flow than any other day in the month and a correspondingly high concentration for TN and TP. That one outlier illustrates the difference between the two methods for these two plants—the current method would reflect the higher load.

Table : Comparison of two methods for calculating average monthly loads for the Alexandria ASA Advanced WWTP. The number of samples per month is equivalent to the number of days in the month. The flow is the average flow for the month; the calculations used the daily flow values.

[8] Note that the conversion factor used in the analyses in this report is 8.344, which is consistent with the factor used by the Chesapeake Bay Program. Virginia uses 8.345 under the current general permit. Maryland uses 8.34. The 8.345 factor is recommended by the American Society of Civil Engineers and is commonly used in other EPA calculations for average daily load.

		Loads calculated on a daily basis, then averaged for month		Loads calculated from monthly average concentration (mg/L) and monthly average flow (MGD)		Change from the current method	
Date	**Flow rate (MGD)**	**TN ave. monthly** (Lbs)	**TP ave. monthly** (Lbs)	**TN ave. monthly** (Lbs)	**TP ave. monthly** (Lbs)	**Percent difference-TN**	**Percent difference-TP**
Jan-2010	37.08	34,175	423	34,310	421	0.39%	-0.53%
Feb-2010	44.90	58,912	480	58,973	450	0.10%	-6.33%
Mar-2010	45.17	52,795	1,217	52,691	1,148	-0.20%	-5.70%
Apr-2010	36.94	45,225	810	45,313	820	0.19%	1.23%
May-2010	34.51	30,283	774	30,550	776	0.88%	0.26%
Jun-2010	33.04	22,600	698	22,882	710	1.25%	1.70%
Jul-2010	31.75	31,764	646	31,578	640	-0.58%	-0.96%
Aug-2010	30.67	28,567	371	28,662	371	0.33%	0.02%
Sep-2010	29.95	28,264	633	27,661	600	-2.13%	-5.26%
Oct-2010	34.23	29,903	978	29,644	971	-0.87%	-0.72%
Nov-2010	33.83	38,716	542	38,644	536	-0.19%	-1.05%
Dec-2010	31.54	33,963	307	33,713	305	-0.74%	-0.56%
Annual average	**35.30**	**-**	**-**	**-**	**-**	**-0.13%**	**-1.49%**
Annual total	**-**	**435,167**	**7,879**	**434,621**	**7,747**	**-**	**-**

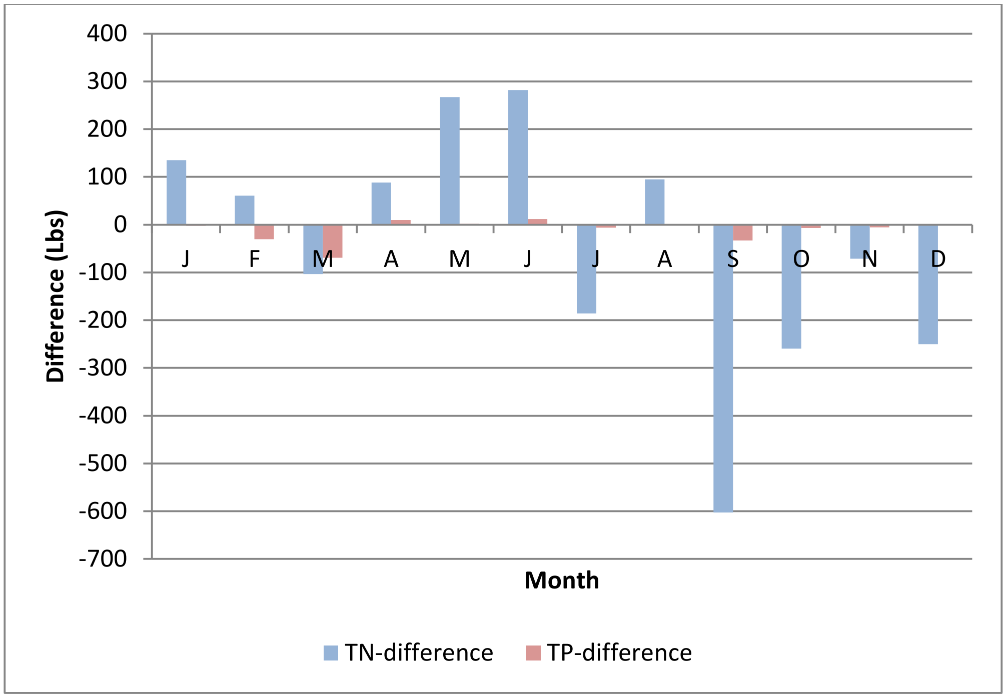


Figure : Difference in loads calculated two ways for the Alexandria ASA Advanced WWTP 2010.

Table : Comparison of two methods of calculating average monthly loads for the Harrisburg WWTP. The number of TP samples per month is equivalent to the number of days in the month. The number of TN samples per month is equivalent to the number of weeks in the month. The flow is the average flow for the month; the calculations used the daily flow values.

		Loads calculated on a daily basis, then averaged for month		Loads calculated from monthly average concentration (mg/L) and monthly average flow (MGD)		Change from the current method	
Date	**Flow (MGD)**	**TN ave. monthly (Lbs)**	**TP ave. monthly (Lbs)**	**TN ave. monthly (Lbs)**	**TP ave. monthly (Lbs)**	**Percent difference -TN**	**Percent difference -TP**
Jan-2010	26.9	111,849	10,089	113,175	10,844	1.19%	7.48%
Feb-2010	23.5	98,371	8,815	97,297	8,968	-1.09%	1.73%
Mar-2010	30.1	104,557	9,317	113,159	9,580	8.23%	2.83%
Apr-2010	21.7	100,427	9,609	105,380	9,770	4.93%	1.67%
May-2010	24.8	99,425	9,409	102,277	9,985	2.87%	6.13%
Jun-2010	19.8	116,528	9,455	108,497	9,456	-6.89%	0.00%
Jul-2010	19.8	110,261	8,335	102,002	8,567	-7.49%	2.78%
Aug-2010	19.2	85,296	8,323	92,436	8,571	8.37%	2.97%

		Loads calculated on a daily basis, then averaged for month		Loads calculated from monthly average concentration (mg/L) and monthly average flow (MGD)		Change from the current method	
Date	**Flow (MGD)**	**TN ave. monthly (Lbs)**	**TP ave. monthly (Lbs)**	**TN ave. monthly (Lbs)**	**TP ave. monthly (Lbs)**	**Percent difference -TN**	**Percent difference -TP**
Sep-2010	18.4	125,507	7,523	99,195	8,009	-20.96%	6.45%
Oct-2010	22.0	120,327	8,726	122,401	9,054	1.72%	3.76%
Nov-2010	19.5	106,089	7,667	91,791	7,852	-13.48%	2.41%
Dec-2010	21.9	108,538	8,628	105,550	9,448	-2.75%	9.51%
Annual average	**22.3**	**-**	**-**	**-**	**-**	**-2.11%**	**3.98%**
Annual total	**-**	**1,287,175**	**105,896**	**1,253,159**	**110,102**	**-**	**-**

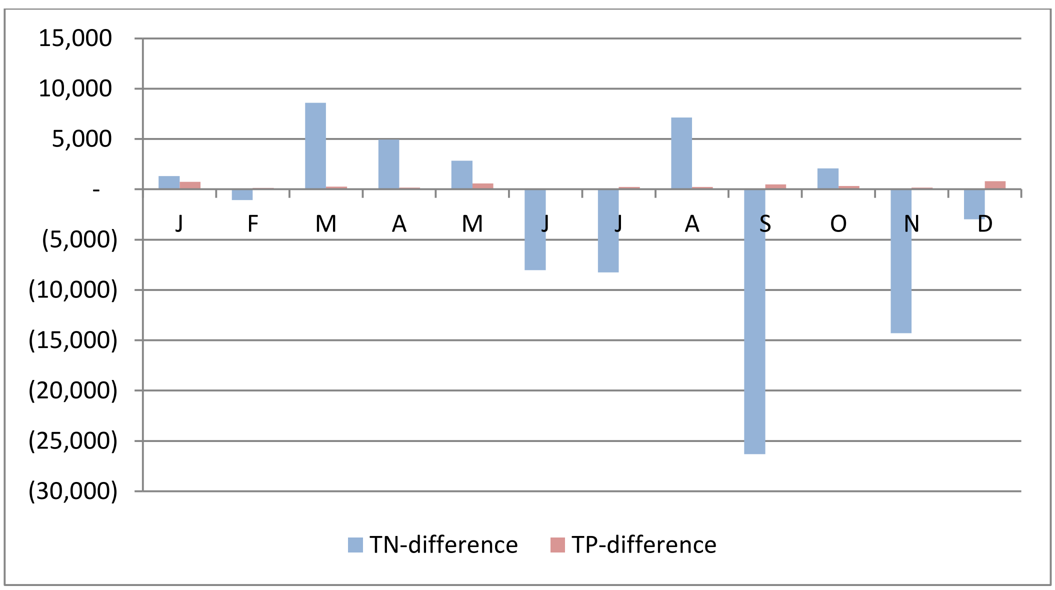


Figure : Difference in loads calculated two ways for the Harrisburg WWTP 2010.

DISCUSSION OF ANALYSES OF THE ALEXANDRIA ASA ADVANCED TREATMENT AND HARRISBURG WWTPS AND FUTURE RESEARCH CONSIDERATIONS

This discussion and analysis is based upon the data from the Alexandria, Virginia ASA Advanced Treatment and Harrisburg, Pennsylvania WWTPs. Results from the analyses of both plants are consistent with each other and may be representative of facilities with similar design flows, those greater than 20 MGD. The correlations between flow, loads, and seasonality were not strongly identifiable. This is to be expected since the TN and TP already had been treated.

This analysis did not take into consideration deliberate sampling bias on behalf of the operator and assumes well operated and controlled plants, which is typical of the larger WWTPs in the Chesapeake Bay watershed Because process control and nutrient control measures are often less sophisticated at WWTPs with flows less than 20 MGD, deliberate sampling bias is considered in these recommendations. Treatment for phosphorus is simpler to manage because phosphorus can be treated as a physical process. Treatment generally includes sorbing the phosphorus to particles and then dropping those particles out of suspension with an additive such as alum. The treatment for nitrogen is more complex and requires biological processes which can be more challenging to manage. As a result, a plant's adjustment to treat a fluctuation of phosphorus levels is generally much faster than the plant's adjustment to a fluctuation in nitrogen levels. Because loads are variable, and reaction times to treatment vary, it is possible to preferentially sample at times when loads are lower.

The analyses indicated that three samples per week for TN and TP decrease error below five percent for these two plants, even if samples were taken primarily when treatment was optimal. The value of sampling more frequently is to reduce variability in samples and avoid effects from preferential sampling. Evaluation of a tolerable level of error was not part of this analysis.

Costs were considered as a factor in determining sampling frequency. Increasing sampling to three times a week from one time a week leads to an annual increase in costs from $3,900 to $11,700 using the average sampling cost of $75 per sample for nitrogen and phosphorus. For this reason, plant operators may prefer to use a weekly flow-weighted composite sample, rather than analyze three samples a week. The decrease in error for sampling more than four times a week is unlikely to justify the increased cost of sampling at either WWTP. Actual costs may differ from the $75 used in this analysis because NPDES-permitted facilities are likely to sample for multiple pollutants other than TN and TP and to sample at a frequency that would allow a contract that delivers a lower cost than an a la carte price.

To determine the real cost of increased sampling, the cost of treating pollution once delivered to the Chesapeake Bay would need to be determined. The difference in treatment cost from once a week to three times a week $11,700 - $3,900 = $7,800 per year (calculated by multiplying the once a week sampling cost of $75 by 52 weeks in a year subtracted from the three times a week cost of $225 multiplied by 52 weeks in a year). Balancing the increase in accuracy for credit calculation against the fairly moderate cost of treatment of nitrogen and phosphorus removal from the delivered load to the Chesapeake Bay indicates that the increase in WWTP sample costs is likely worthwhile.

Of the two methods assessed for calculating loads, the method currently used in Virginia and Pennsylvania is valid for its intended purpose because it is the more cautious approach. Continued use of the current method for these two WWTPs predicts higher loads when sampling frequency was daily. Flow for both facilities was substantially higher than any other day for September 30, 2010. The reason was heavy rainfall across the northeastern US and Mid-Atlantic due to Hurricane Nicole and a synoptic low pressure zone (http://www.erh.noaa.gov/aly/Past/2010/Sep30-Oct01_2010/Sep30-Oct01_2010.htm). The currently-used load calculation method was more sensitive to outliers, such as this storm event, and is the more conservative method for protecting water quality. The results between the two plants in this analysis, Harrisburg and Alexandria WWTPs, are similar. Future analyses might find differences among NPDES-permitted facilities that treat different sources of waste and have different design flows. Future analyses should consider grouping various types of plants together for analysis. For example, facilities that treat combined sewer overflows may behave differently than industrial, municipal or power plants. WWTPs with design flows of less than 0.05 MGD are likely to perform differently than those with design flows of greater than 25 MGD. Additional exploration into why various days of the week have significantly different loads for the Harrisburg WWTP also may be beneficial. The difference in loads among days of the week does not affect the analysis of sampling frequency. However, the difference may affect when the sample is taken—on a day with historically higher loads versus a day with historically lower loads—to avoid sampling when concentrations are lower.

This evaluation uses the concentration data as sampled, not back-calculated from loads. The Harrisburg WWTP data that PaDEP originally provided had concentrations back-calculated from loads. This approach is suspect because the average monthly loads calculated from the back-calculated concentrations are in some cases dissimilar to the average monthly loads calculated from the original concentration data. Therefore, EPA expects that concentration data be checked to make sure that it is not back-calculated or otherwise processed prior to determining average monthly loads.

SUMMARY OF EXPECTATIONS AND RECOMMENDATIONS

The following expectations and recommendations address the impacts of sampling frequency and post-treatment load calculation methodology on TN and TP load results. The analyses of the Virginia and Pennsylvania WWTPs are used to inform the recommendations for WWTPs involved in offsets and trading in the Chesapeake Bay watershed.

1. **EPA's expectation is that WWTPs involved in offsets and trading in the Chesapeake Bay watershed will adopt a load calculation methodology and sampling frequency sufficient to support Chesapeake Bay jurisdictions' trading and offset programs.**

2. The monthly load is found by averaging the loads as calculated below for each sample in the month. **EPA expects that the monthly load is calculated using the actual discharge and concentration as sampled.** Concentration values should not be used when those concentration values were derived from loads (pounds). Rather, the sampled concentration data should be used in the monthly load calculation.

3. This technical memorandum also assessed bias in average monthly loads for two different calculation methods. The analysis suggests that the current calculation methodology for loads is valid for its intended purpose. **EPA recommends that the Chesapeake Bay Partnerships' Wastewater Treatment Workgroup evaluate whether the factor 8.344 should be changed to 8.345 and whether loads should be calculated for each sample as follows:** Daily load (Lbs) = concentration (mg/L) * flow (MGD) * 8.345

The current data set indicates that this method is more conservative as it reflected the higher load.

However, should the Bay jurisdictions have a history of using a different and previously accepted calculation method and/or conversion factor, then the Bay jurisdictions' alternative method will be acceptable to maintain consistency in comparisons of loads over time.

4. The analyses presented here did not take into consideration deliberate sampling bias on behalf of the operator. Separate analyses were conducted of data from multiple facilities with the requirement of one weekly composite sample and varying levels of flow. These analyses indicated load variations of greater than one order of magnitude at the same facility in similar monthly flow regimes. From a compliance

standpoint, this is problematic. While regulatory agencies have the ability to independently verify plant compliance when dealing with maximum and weekly average concentrations, regulatory agencies do not have that ability when dealing with annual loads. For an oversight agency to demonstrate whether the facility was in actual compliance with its annual limits, the agency would have to sample until such time the facility violated the limit. This is not practical, and so it is important that the sampling frequency be sufficient so as to minimize any attempt to bias the sampling by sampling at non-representative conditions**. EPA provides recommendations in the following two paragraphs regarding sufficient sampling frequency.**

This assessment, in combination with concerns about preferential sampling, indicates that three or more samples per week are likely to decrease error below five percent for both TN and TP, even where preferential sampling is in use. EPA has determined that less than 5% error is a substantial improvement, and is acceptable at this time. Sampling frequency of at least three times a week for both TN and TP would generate data sufficient to support credit calculation for the purposes of water quality offset and/or trading programs. Thus, NPDES-permitted facilities or aggregators could use discharge monitoring report monthly average load data to determine the number of credits required to offset loads for plants sampling three or more times per week. The three samples per week also would provide a higher degree of confidence that sources were in compliance with their permit limits. In addition, the discharger should be required to maintain adequate documentation on operating conditions and chemical addition so as to allow the inspector to determine whether the sampling is occurring at representative conditions.

As an alternative, the permitting agency could use a three day to weekly flow-weighted composite sample. "Composite sample" means a combination of individual samples obtained at hourly or smaller intervals over a time period. Either the volume of each individual sample is proportional to discharge flow rates or the sampling interval (for constant volume samples) is proportional to the flow rates over the time period used to produce the composite. This could increase the certainty of the calculated annual load while at the same time remove any additional analysis costs. This method would require demonstration to be acceptable for use. Since there are numerous permittees with design flows less than 20 MGD and who may only operate seasonally, a composite sample may be more affordable and practical. Additionally, when dealing with particularly small dischargers a less rigorous sampling frequency may be appropriate.

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