Impact of Treatment Type on Municipal Wastewater Treatment Effluent Nutrient Concentrations in the Delaware River Basin

DELAWARE RIVER BASIN COMMISSION

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July 2016

Acknowledgements

This report was prepared by the Delaware River Basin Commission staff: Steven J. Tambini, P.E., Executive Director. John Yagecic was the principal author of the report. Mr. Yagecic is the Manager of Water Quality Assessment at DRBC and a licensed professional engineer. Substantial technical contributions were made by David Sayers, formerly of DRBC, Pamela V'Combe, Water Resource Planner, Shane McAleer, PE, Water Resource Engineer, and Chad Pindar, PE, Manager, Water Resource Planning. Eric Wentz, Elaine Panuccio, and Julia Ragazzo provided technical assistance. Technical recommendations and support were provided by Thomas Fikslin, Karen Reavy, Namsoo Suk and Steve Walsh.

Suggested Citation

Yagecic, J.R., Sayers, D., V'Combe, P.J., McAleer, S., and Pindar, C. 2016 Impact of Treatment Plant Type on Point Discharge Effluent Nutrient Concentrations in the Delaware River Basin. Delaware River Basin Commission. West Trenton, NJ. July 2016.

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Background and Introduction

One of the ongoing challenges in crafting nutrient management approaches is quantifying the relative point discharge contributions to the overall nutrient load. An understanding of typical effluent nutrient concentrations is necessary for establishing default loads for discharges without monitoring data for water quality models and for assessing the achievability of proposed effluent nutrient limits.

In its web page entitled *Action towards Limiting Total Nitrogen, Total Phosphorus, and Total Inorganic Nitrogen Loads from NPDES-Permitted Facilities*, EPA documented the relative sparseness of nutrient monitoring data from NPDES permitted facilities (EPA, 2014).

Municipal waste water treatment plants differ in their design, capacity, and efficiency in nutrient removal. The engineering design process for waste water treatment utilizes information about influent characteristics and extensive engineering equations and practices to reliably achieve target effluent concentrations of specific pollutants. Actual effluent concentrations, however, fluctuate in response to variations in influent flow and concentrations, plant operation and maintenance, and even weather conditions. Permit writers, surface water modelers, and planners need to know approximate distributions of effluent nutrient concentrations to manage water quality and test claims about limits of achievability.

In its 2014 report, the Delaware River Basin Commission (DRBC) performed an initial assessment of effluent nutrient data submitted by point dischargers in compliance with DRBC permit conditions. This initial report provided descriptive statistics of effluent concentrations of nutrients across all facilities.

In this update, DRBC expands on the 2014 assessment by describing specific characteristics of the waste water treatment facilities, allowing a comparison among secondary treatment types.

DRBC issues permits called dockets (similar to NPDES permits) to wastewater dischargers throughout the Delaware River Basin. In order to demonstrate compliance with applicable effluent limitations and/or monitoring requirements, most modern DRBC wastewater dockets require the submittal of an annual report. This report is known as the annual effluent monitoring report (AEMR). Most wastewater discharge dockets for facilities located in the geographic portion of the Delaware River Basin known as "Special Protection Waters", which is essentially everything upstream of Trenton, NJ, are required to monitor for nutrients. The nutrient data is a critical enabling component for the Commission to implement its Special Protection Waters Program, which is likely the largest continuous stretch of waters in the nation where an anti-degradation program is actively enforced.

AEMR Data

The AEMR data set consists of monthly mean flows, and concentrations and loads of nutrients and related parameters from facilities in the Delaware River Basin submitting effluent monitoring reports to the DRBC. The compiled data set described in this report includes nutrient monthly mean concentrations from 154 facilities, spanning a time frame from 2007 through 2014. The number of facilities submitting AEMRs has increased over time, resulting in a higher density of data toward the end of that period. Figure 1 below shows a typical AEMR report form. Note that monitoring requirements differ from facility to facility so that most facilities are not required to monitor every parameter.

Year: 2011	DRBC Annual Effluent Monitoring Report
Docket Holder:	XXXXX XXXXXXXXXX
Docket Number:	X-XXXX-XXX-X
NPDES Number:	XXXXXXXXX
Outfall Number:	1
Docket Approval Date:	XX/XX/XXXX
Docket Expiration Date:	XX/XX/XXXX

DRBC Mail Control Slip Number (DRBC USE ONLY):	email 8/27/2012
	Date Form Edited: 5/30/2012

Docket holders should begin by entering the calendar year being reported. The docket holder's name should be the same as the one on the actual docket. Docket and NPDES permit numbers must be entered on the form, or the Annual Effluent Monitoring Report will not be associated with the docket and may result in a compliance issue.

Applicability: BW = Basinwide, SPW = Special Protection Waters, SS = Special Study		BW, SPW		BW, SPW	BW, SPW		BW, SPW		BW		BW	BW		SPW	SPW		SPW		SPW		SPW		OTHER		SS		SS	SS	SS
Enter Monitoring Requirements from Docket	Average Monthly Flow	Total Suspended Solids		Fecal Coliform	Ammonia - Nitrogen		CBOD (5-day) or BOD (5-day)		pH		Color	Total Dissolved Solids		Dissolved Oxygen	Total Phosphorous		Total Kjeldahl Nitrogen		Nitrate - Nitrite - Nitrogen		Total Nitrogen				CBOD20		Specific Conductivity	Acute Toxicity	Chronic Toxicity
Units	mgd	mg/l	lbs/d	cfu / 100 ml	mg/l	lbs/d	mg/l	lbs/d				mg/l	lbs/d	mg/l	mg/l	lbs/d	mg/l	lbs/d	mg/l	lbs/d	mg/l	lbs/d			mg/l	lbs/d	µS/cm	LC_{50} %	IC_{25} %
Monthly Average Effluent Limit (Winter-Spring)	5.7	30	1426	200	2.22	106	10	475	6 -- 9					7															
Monthly Average Effluent Limit (Summer-Fall)	5.7	30	1426	200	0.74	35	5	238	6 -- 9					7															
Monitor & Report Only																													
Enter Monitoring Results 2011	Report Monthly Average	Report Monthly Average		Report Monthly Average	Report Monthly Average		Report Monthly Average; Indicate CBOD5 vs. BOD5 CBOD5		Report Monthly Minimum	Report Monthly Maximum	Report Monthly Average	Report as directed in docket		Report Monthly Average	Report Monthly Average		Report Monthly Average		Report Monthly Average		Report Monthly Average				Report Monthly Average		Report as directed in docket	Report as directed in docket	Report as directed in docket
January	2.849	6.1	147.8	8	0.19	4.2	4.1	96.2	7	7.5				9.8					10.6	210.5									
February	4.843	5.6	227.2	19	0.16	6.8	4.5	180.9	7	7.2				10.3					12	417.8									
March	5.154	4.9	230.5	14	0.38	15.9	4.2	185.1	7	7.5				10.3					10.2	358.3									
April	4.641	4.8	198.4	6	0.26	9.3	3.1	123.4	7.1	7.5				10.1					9.6	253.5									
May	3.484	4.4	126.6	10	0.28	7.5	3.5	102.3	7.1	7.6				9.5					8.5	226.1									
June	2.843	6.2	142.4	66	0.3	6.9	3.4	78.2	7.2	7.6				8.7					13.8	332.2									
July	2.683	3.8	85.3	44	0.12	2.6	3	68.1	7.2	7.7				8.3					15.3	335.8									
August	3.521	3.8	133.7	68	0.11	3.6	2.9	91.2	7.2	7.9				8.5					16.6	373.4									
September	4.797	3.4	163.9	26	0.11	4.8	2.4	101.4	7.1	7.6				8.9					9.6	501.8									
October	3.491	2.6	77.6	27	0.1	2.9	2	59	7.2	7.7				9.2					4.8	176.3									
November	3.863	4.3	152.6	12	0.1	3.2	2.4	78.9	7.3	7.7				9.4					9	371.8									
December	4.102	6.2	217	10	0.1	3.5	3.1	106.4	7.1	7.5				10.1					14.9	392.6									

Docket Holder Comments:

Figure 1. Sample AEMR Report

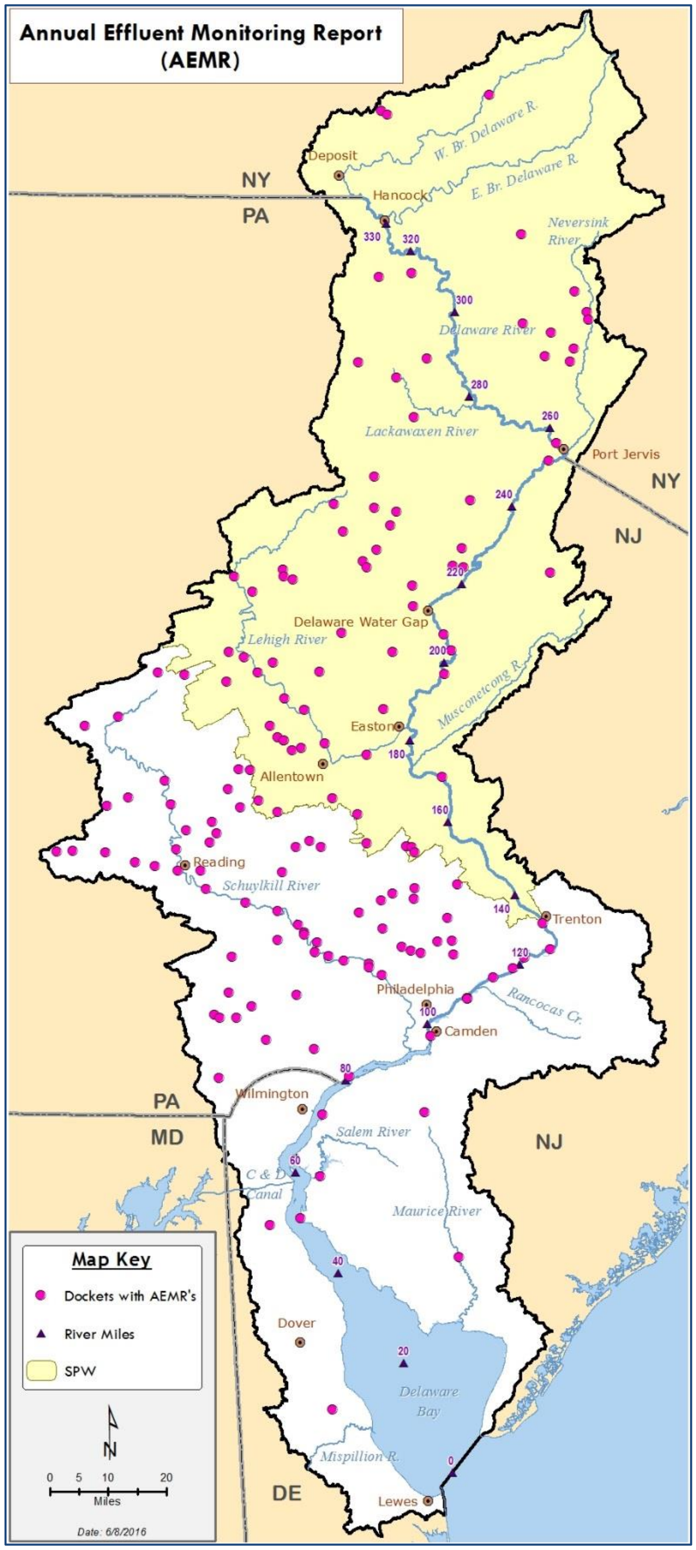


Figure 2. Map of Facilities in this AEMR Data Set

Data Caveats

The current AEMR data set may provide a sense of *typical* effluent values for wastewater treatment facilities by months of the year for the parameters reported. However, there are limitations to the data that users should consider:

- Monthly values provided by docket holders are monthly means, rather than discrete sample results. The discrete values used to derive the monthly means were not reported. In addition, the number of discrete samples contributing to each mean is likely to be different from facility to facility, and may be also be different by season. As such, it is probably infeasible to make inferences about the variability of discharge concentrations from this data;
- Defining the low concentration end of each parameter was hampered by the occasional reporting of non-detect values, and uncertainty regarding exactly what these non-detects represented. For example, if a facility was computing a monthly mean from four discrete observations, it is unclear how facilities would interpret a mix of non-detect and quantified observations for the same month. A detailed description of handling non-detect values is provided in the following section;
- The parameter TN may be a direct measurement or it may be the summation of other measured nitrogen species. The AEMR form does not capture which version is being reported;
- Defining the high concentration end of each parameter was hampered by the occasional reporting of values that appeared to exceed likely upper limits based on best professional judgment.

As a consequence of the uncertainties at the high and low concentration ends of the range, we decided to focus on the interquartile range (25^{th} percentile, median, and 75^{th} percentile) to represent the central tendency of the data. The plots shown in later in this report are modified boxplots, excluding whiskers and outliers (outside the interquartile range).

Data Extraction and Processing

AEMRs are submitted by docket holders as formatted Microsoft Excel spreadsheets with data validation controls. Two internally developed computer programs were used to identify files matching the format of submitted AEMRs and copy the submitted data to a database. The first program crawled through all folders and subfolders potentially containing a submitted AEMR, and identified spreadsheets matching the AEMR format, regardless of file name. The second program copied the submitted effluent values into a centralized data spreadsheet.

Both programs were executed in early 2015, capturing data submitted up to that point.

Simultaneously, DRBC staff reviewed DRBC dockets issued to the facilities submitting data. From the dockets, staff extracted descriptions of the following:

- Plant type (WWTP, IWTP, or Water filtration plant);
- Descriptions of secondary treatment process;
- Descriptions of tertiary treatment or treatment augmentation (such as influent flow equalization, polishing, or effluent nutrient removal);
- Plant capacity; and
- Inclusion in Special Protection Waters (SPW) watersheds.

Initial review suggested that Industrial waste treatment varied greatly in its treatment type, influent source, and the proportion of influent that was stormwater runoff. We determined that this high degree of variability would result in data of limited usefulness. We excluded IWTP plants and data from further evaluation.

Municipal plants *being upgraded* typically reflected an extended transition from an older to newer treatment process. We excluded these plants to eliminate the ambiguity associated with interim or uncertain treatment processes. For instances where a plant was up-rated (approved for a higher treatment volume) but without specific physical modification, the higher capacity was used. Although data was provided on water filtration plant backflow discharges, this waste stream was not evaluated.

In the period between the 2014 report and the preparation of this report, DRBC staff routinely screened submitted AEMR reports and resolved the data ambiguities with the submitter for current and past reports. As a result, the rate of data cleaning was much lower in this iteration. Data cleaning included:

- Blank or missing values were replaced with *NA*, the default nomenclature of the processing software;
- Obvious errors were replaced with *NA*. There were very few incidents of this type of replacement, usually resulting from a note in the form cell, rather than a value;
- Non-numeric entries with no obvious interpretation (such as ***) were replaced with *NA*. Again, relatively few replacements of this type were required.
- Docket holders employed different formats to indicate monthly means below a reporting limit. In the data cleaning process, we addressed these edited values using the approaches below:
    - Entries reported as less than some value *X*, were set equal to that value *X*. For example, a monthly mean reported as <0.2 was replaced with 0.2;
    - Entries indicating an attempted measurement, for which no lower limit value could be inferred (such as "Not detected" or ND) were set equal to NA.
- Reported values of zero represented uncertain data. Labs typically report non-detected, below detection limit, or flagged values, but not zero. It is unclear whether these reported zeros represented a non-detect result, an indication that the parameter was not monitored, or something else. To minimize the impact of these uncertain zeros, we converted these to NA (thus excluding them). The rates of conversion from zero to NA are as provided below:
    - Ammonia: 164 values of 0 converted to NA out of 6560 reported

- CBOD5 or BOD5: 246 values of 0 converted to NA out of 7212
- TDS: 165 values of 0 converted to NA out of 4272
- DO: 60 values of 0 converted to NA out of 3936
- Phos. Total: 117 values of 0 converted to NA out of 3679
- TKN: 93 values of 0 converted to NA out of 1388
- Nitrate + Nitrite: 186 values of 0 converted to NA out of 2422
- Total N: 140 values of 0 converted to NA out of 1671

No upper end values were eliminated as outliers, although a handful of reported monthly means for each parameter appear to be unreasonably high. We reviewed the distribution of each parameter to determine if there was a threshold that would indicate obvious error for values above that threshold. This review was inconclusive, however, and we opted to retain all values and defer development of acceptable value ranges to future phases of work.

Data cleaning and initial processing was performed in Microsoft Excel. After cleaning, data interpretation and processing was performed using the R statistical programming software, as implemented in R Studio (Version 0.99.902 running R version 3.3.0 (2016-05-03)).

Manual Screening to Determine Accuracy of Automated Data Compilation

Since the data was harvested from individual reports using an automated process, we performed a manual screening of a subset of results to gain insight into the likely rate of error associated with the automated process. We randomly selected 5% of all compiled records for manual comparison to the original reports submitted. The final result of this screening confirmed that the selected data was correctly transcribed from the AEMR reports.

Results and Discussion

Table 1 below shows available data after cleaning and number of facilities reporting for Ammonia Nitrogen (mg/L), Nitrate-Nitrite Nitrogen (mg/L), Total Nitrogen (mg/L), Total Kjeldahl Nitrogen (TKN) (mg/L), Total Phosphorus (mg/L), Total Dissolved Solids (TDS), BOD(5-day) (mg/L), and CBOD5 (mg/L).

Table 1. Effluent Data and Facility Count

Parameter	n observations (Count of reported monthly mean values)	Unique Facilities reporting
Ammonia N (mg/L)	4194	147
Nitrate + Nitrite (mg/L)	1446	70
N Total (mg/L)	1001	57
TKN (mg/L)	737	48
Phos. Total (mg/L)	2400	97
TDS (mg/L)	2145	141
BOD5 (mg/L)	282	13
CBOD5 (mg/L)	4255	145

We grouped the waste water treatment facilities by secondary treatment category as shown in Table 2 below. Where docket applicants described the secondary treatment type by proprietary treatment names, we used domain specific knowledge and best professional judgment to assign the treatment type to a standard category.

Table 2. Secondary Treatment Categories and Abbreviations.

Secondary Treatment Category	Abbreviation	Facilities in Category
Conventional Activated Sludge	CAS	56
Trickling Filter	TF	16
Sequencing Batch Reactor (SBR)	SBR	31
Rotating Biological Contactor (RBC)	RBC	6
Oxidation Ditch	OD	14
Aerated Lagoons	AL	7
Activated Sludge / Extended Aeration	AS.EA	16
Other/Combined	Other	3
Membrane Bioreactor (MBR)	MBR	5

Selected Nutrient Results by Secondary Treatment Type

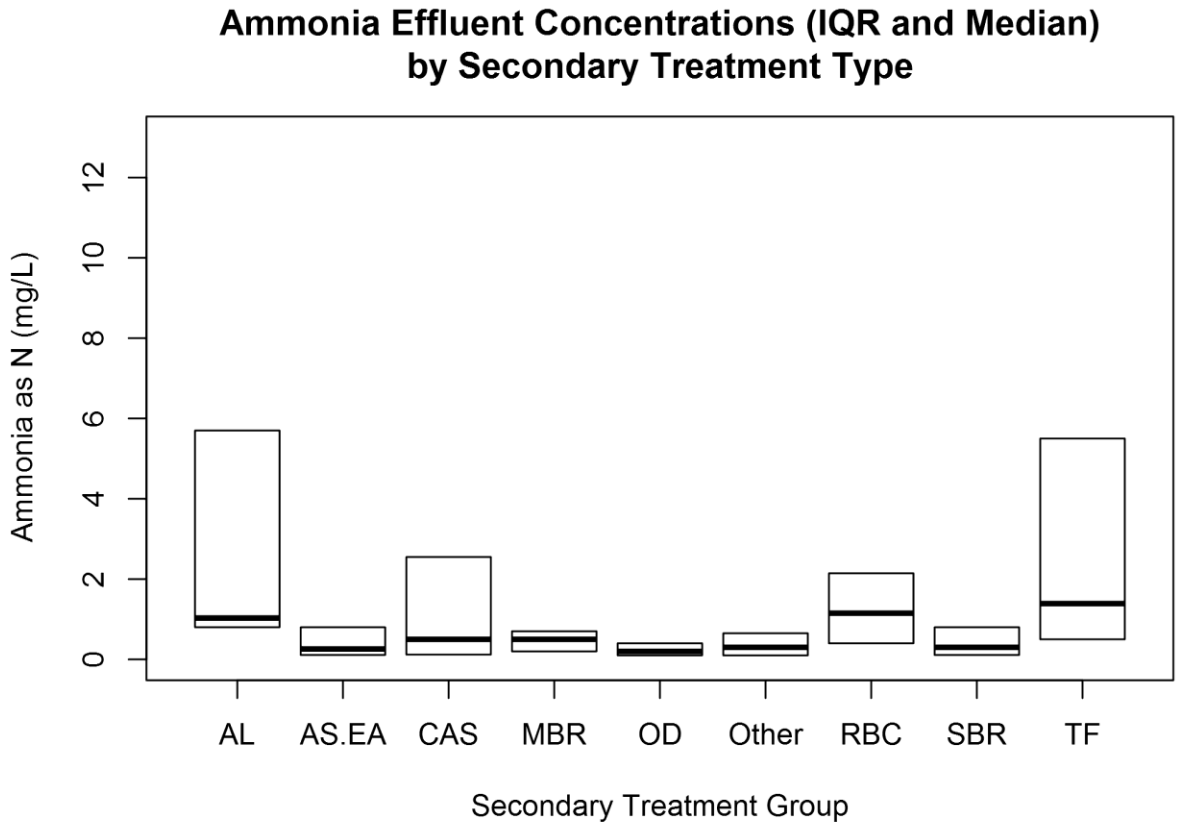


Table 3. Ammonia Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	86	5	0.81	1.03	5.675
AS.EA	615	16	0.11	0.26	0.8
CAS	1628	54	0.12	0.5	2.55
MBR	93	5	0.2	0.5	0.7
OD	518	14	0.1	0.2	0.4
Other	60	2	0.1	0.3	0.625
RBC	103	6	0.4	1.15	2.145
SBR	673	29	0.11	0.3	0.8
TF	418	16	0.5	1.39	5.435

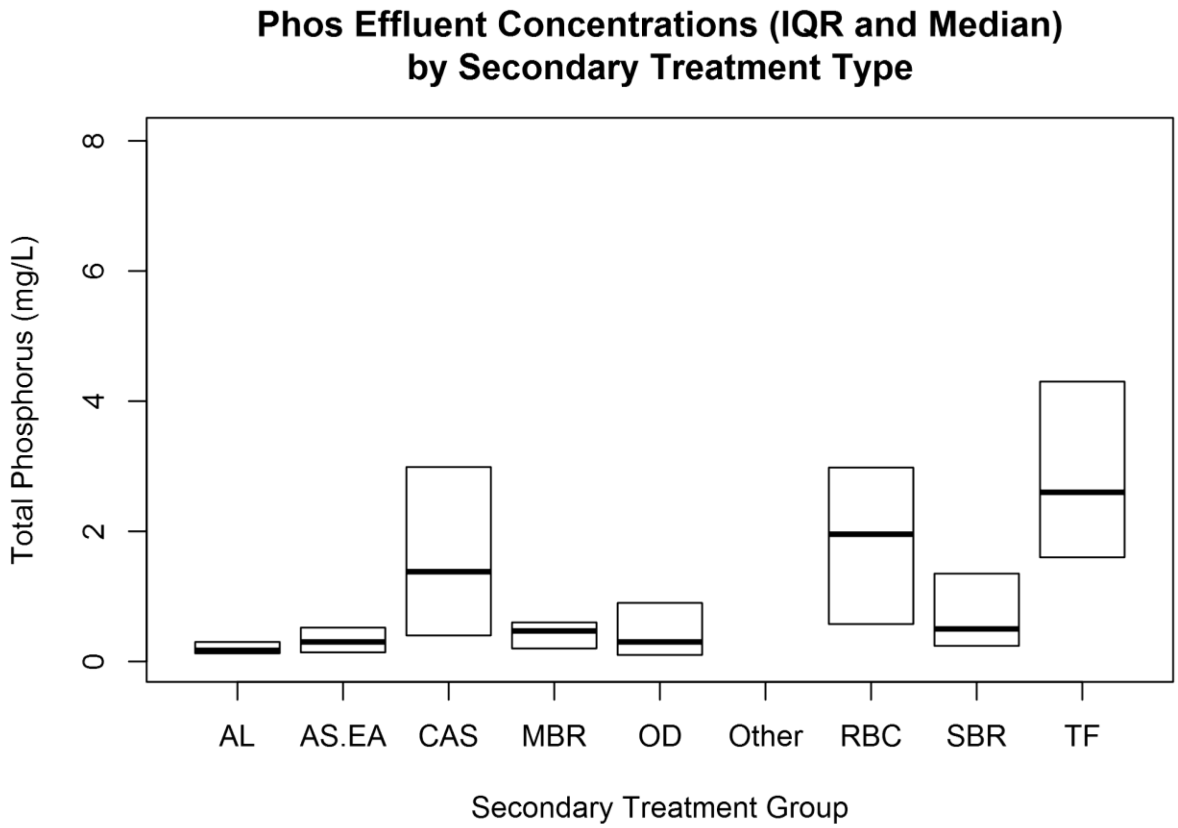


Table 4. Phosphorus Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	42	3	0.12525	0.171	0.297
AS.EA	514	12	0.14	0.3	0.5175
CAS	836	37	0.4	1.38	2.98125
MBR	78	4	0.202875	0.46875	0.6
OD	195	7	0.1	0.3	0.9
Other	NA	NA	NA	NA	NA
RBC	52	3	0.5825	1.955	2.965
SBR	478	22	0.2425	0.5	1.3375
TF	205	9	1.6	2.6	4.3

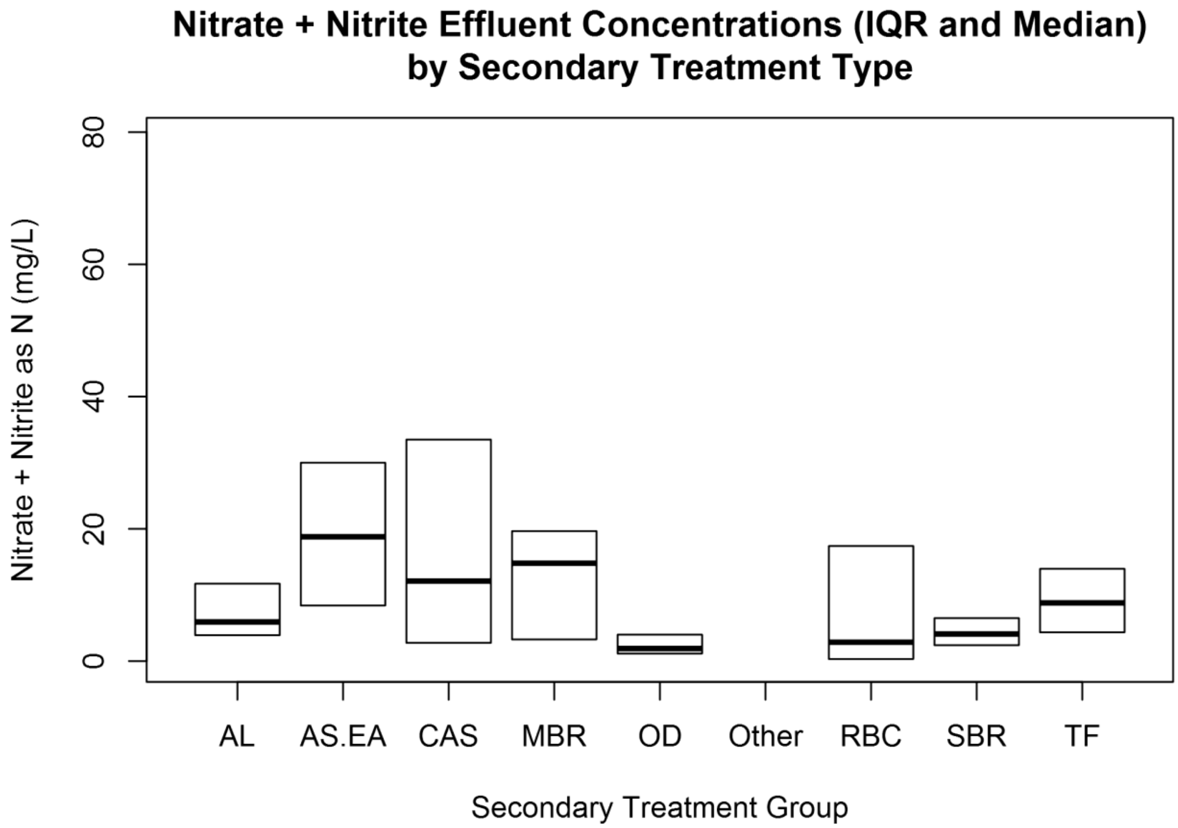


Table 5. Nitrate + Nitrite Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	41	2	3.91	5.92	11.71
AS.EA	226	9	8.4	18.8	29.95
CAS	586	27	2.765	12.1	33.5
MBR	55	4	3.275	14.8	19.65
OD	73	2	1.14	1.9	4
Other	NA	NA	NA	NA	NA
RBC	38	3	0.3125	2.85	17.2
SBR	276	17	2.4	4.1	6.485
TF	151	6	4.35	8.8	13.955

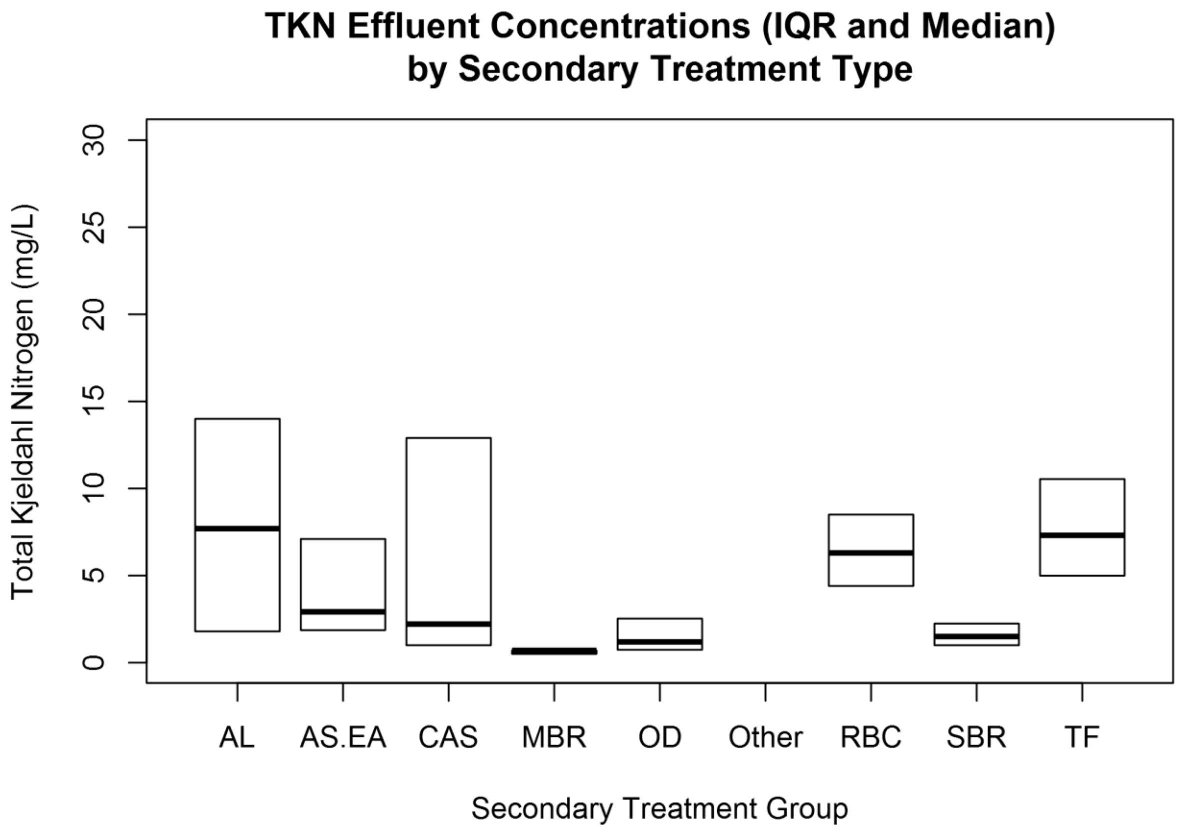


Table 6. Total Kjeldahl Nitrogen Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	43	4	1.795	7.7	14
AS.EA	127	6	1.865	2.92	7.1
CAS	220	15	1	2.215	12.8
MBR	13	2	0.5	0.7	0.7
OD	57	1	0.74	1.19	2.53
Other	NA	NA	NA	NA	NA
RBC	37	3	4.4	6.3	8.5
SBR	140	12	1	1.5	2.22
TF	100	5	5.005	7.31	10.51125

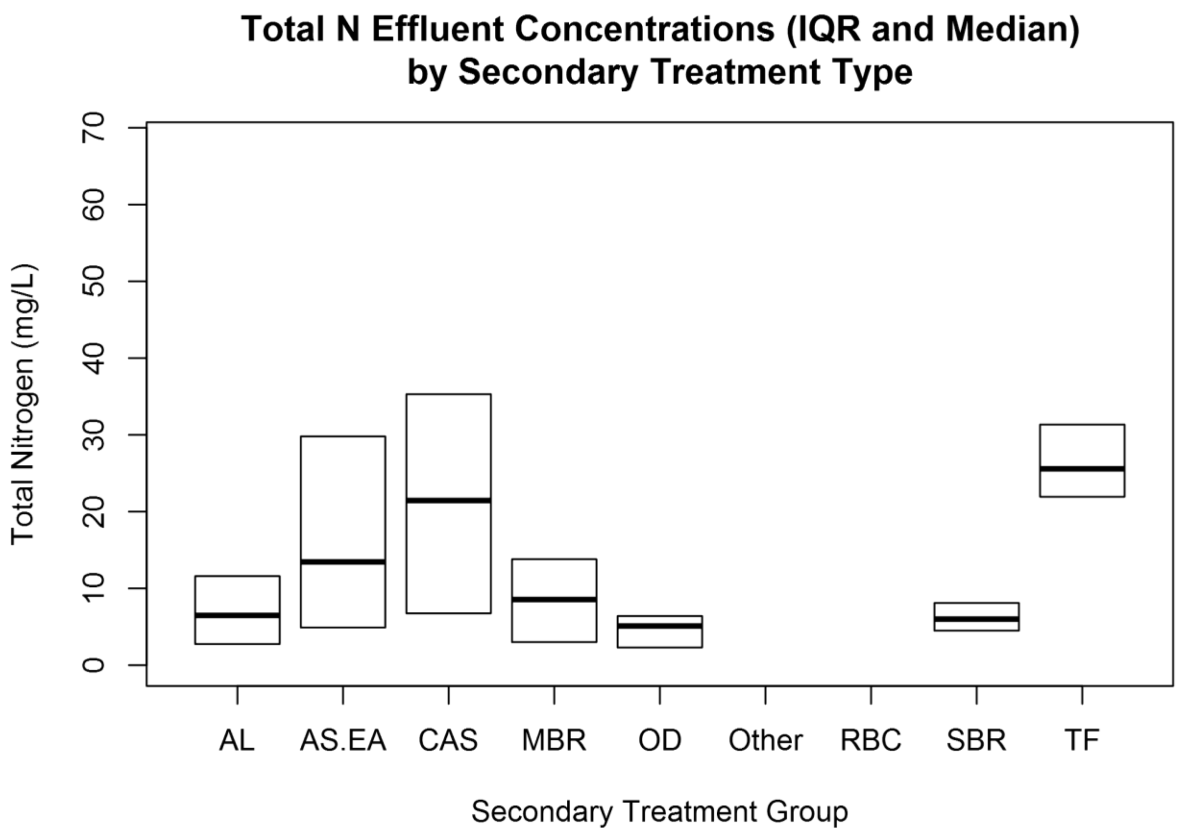


Table 7. Total Nitrogen Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	46	2	2.8325	6.48	11.36
AS.EA	238	9	4.9	13.45	29.725
CAS	258	19	6.87	21.45	35.2
MBR	70	5	3	8.55	13.7
OD	121	4	2.3	5.1	6.4
Other	NA	NA	NA	NA	NA
RBC	NA	NA	NA	NA	NA
SBR	225	14	4.5	6	8.1
TF	43	4	21.935	25.58	31.345

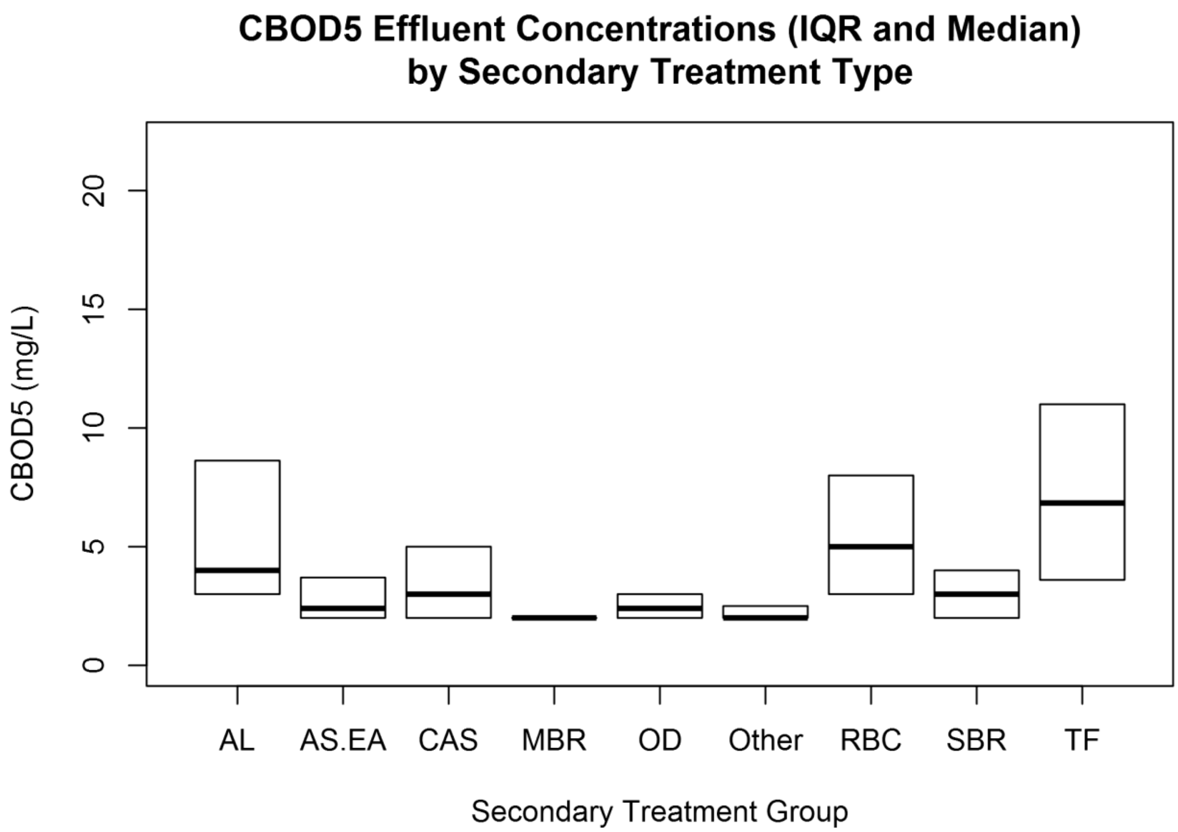


Table 8. CBOD5 Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	131	7	3	4	8.625
AS.EA	670	16	2	2.4	3.7
CAS	1531	52	2	3	5
MBR	105	5	2	2	2
OD	503	12	2	2.4	3
Other	60	2	2	2	2.25
RBC	69	5	3	5	8
SBR	707	30	2	3	4
TF	455	15	3.6	6.84	11

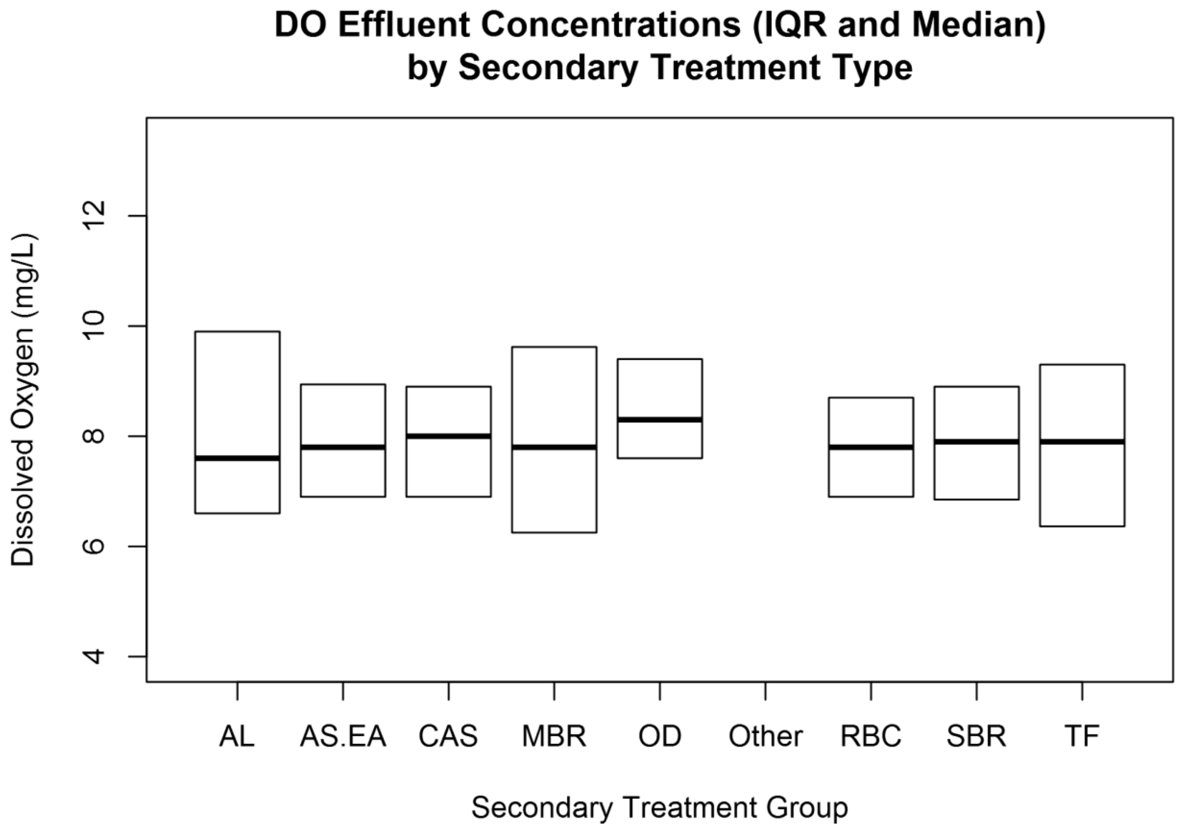


Table 9. DO Effluent Concentrations by Secondary Treatment Category

Secondary Treatment	n	facilities	25th percentile	median	75th percentile
AL	61	4	6.6	7.6	9.9
AS.EA	535	13	6.9	7.8	8.94
CAS	890	34	6.9	8	8.9
MBR	63	3	6.25	7.8	9.62
OD	331	9	7.6	8.3	9.4
Other	NA	NA	NA	NA	NA
RBC	54	3	6.9	7.8	8.7
SBR	498	22	6.855	7.9	8.9
TF	272	10	6.3725	7.9	9.3

Select Results by Month in Conventional Activated Sludge

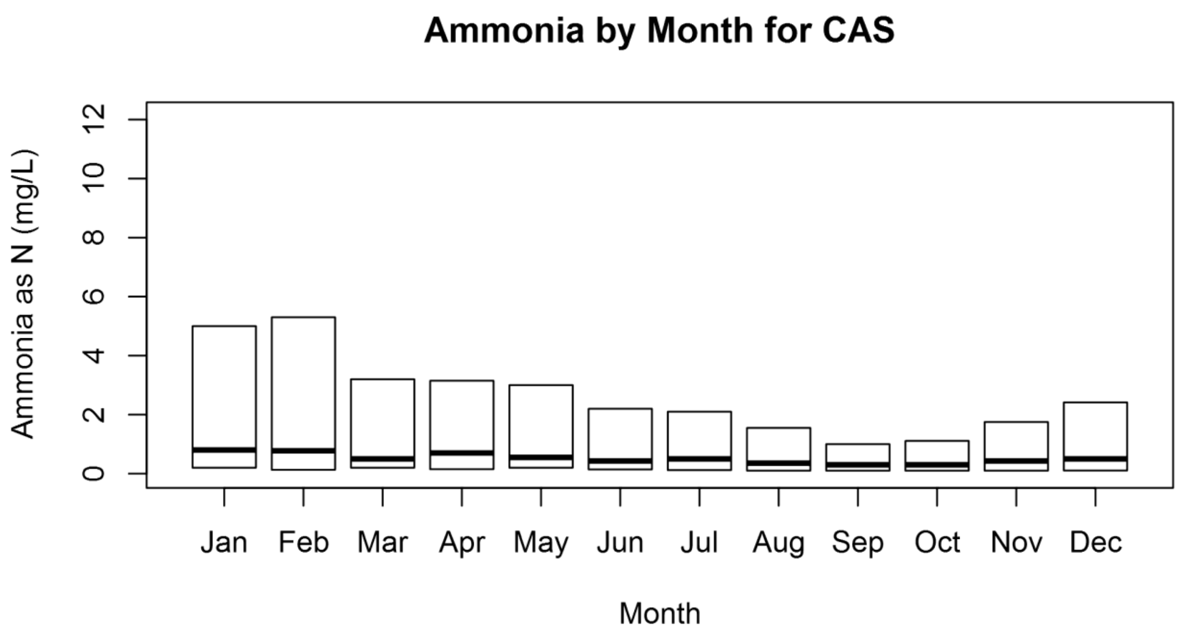


Table 10. Ammonia Effluent Concentrations by Month, Conventional Activated Sludge

Month	n	facilities	25th Percentile	Median	75th Percentile
Jan	133	50	0.2	0.8	5
Feb	130	49	0.1325	0.775	4.975
Mar	130	49	0.2	0.5	3.195
Apr	132	49	0.15	0.7	3.075
May	136	52	0.2	0.55	3
Jun	140	52	0.14375	0.43	2.15
Jul	142	53	0.1205	0.5	2.085
Aug	140	52	0.1	0.355	1.525
Sep	136	52	0.1	0.3	1
Oct	139	53	0.1	0.3	1.11
Nov	135	52	0.1	0.43	1.75
Dec	135	51	0.105	0.5	2.415

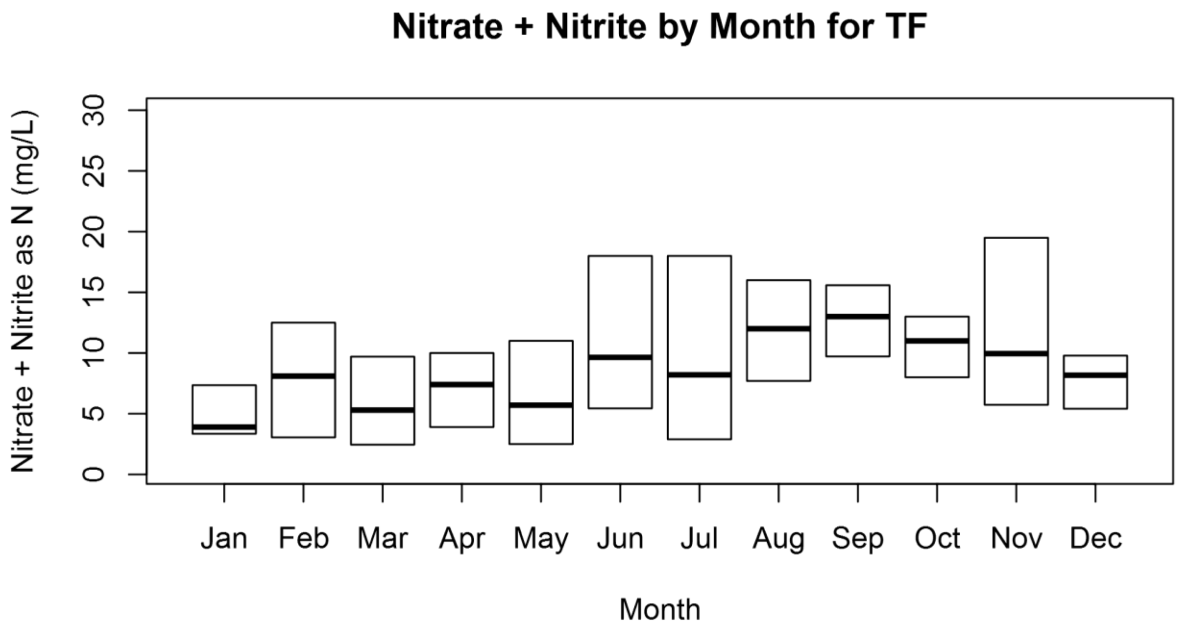
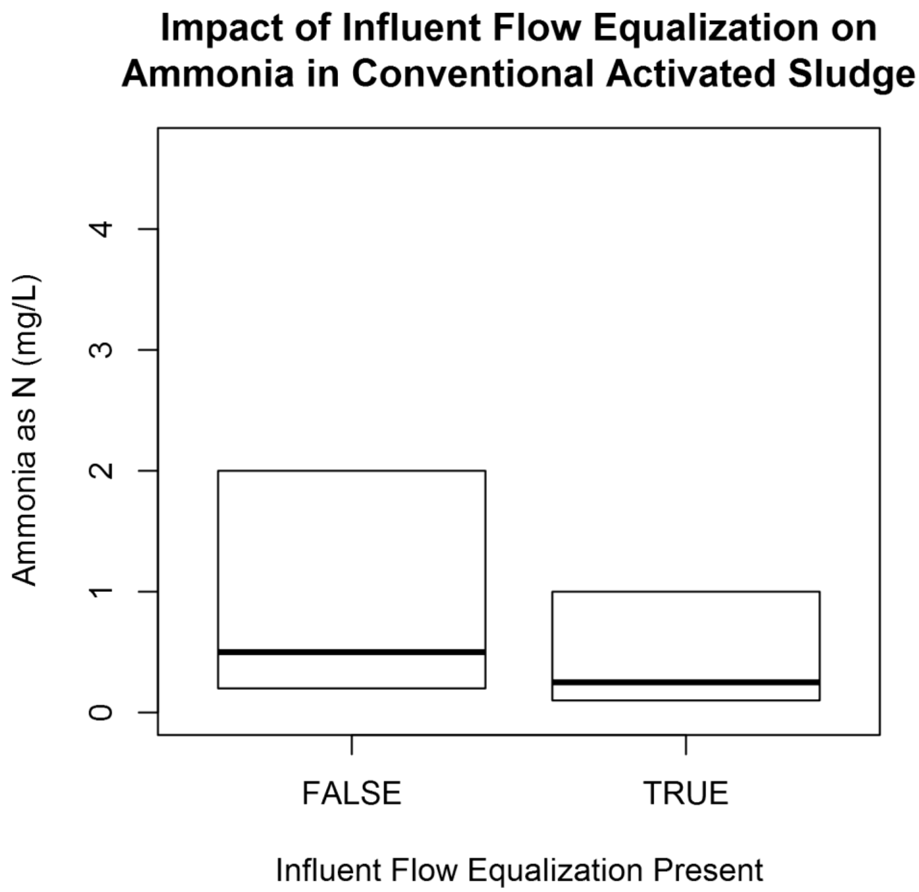


Table 11. Nitrate + Nitrite Effluent Concentrations by Month, Trickling Filter

Month	n	facilities	25th Percentile	Median	75th Percentile
Jan	11	5	3.35	3.9	7.354
Feb	12	5	3.075	8.09625	12.25
Mar	12	5	2.575	5.3	8.05
Apr	13	6	3.9	7.4	10
May	13	6	2.5	5.7	11
Jun	13	6	5.44	9.64	18
Jul	13	6	2.89	8.2	18
Aug	13	6	7.7	12	16
Sep	13	6	9.72	13	15.58
Oct	13	6	8	11	13
Nov	12	6	5.7525	9.95	18.245
Dec	13	6	5.41	8.17	9.785

We also looked at the impact of tertiary treatment on effluent ammonia concentrations for facilities using conventional activated sludge. Although the impact may be substantial, there are too few facilities using tertiary treatment to draw conclusions.

Impacts of Equalization and Filtration on Ammonia in Activated Sludge



The presence of flow equalization at conventional activated sludge treatment plants did appear to make a substantial difference in effluent ammonia concentrations, particularly at the upper quantile.

Table 12. Observations and Facility Count for Flow Equalization in Conventional Activated Sludge

Equalization Present	n	Unique Facilities
True	848	26
False	752	25

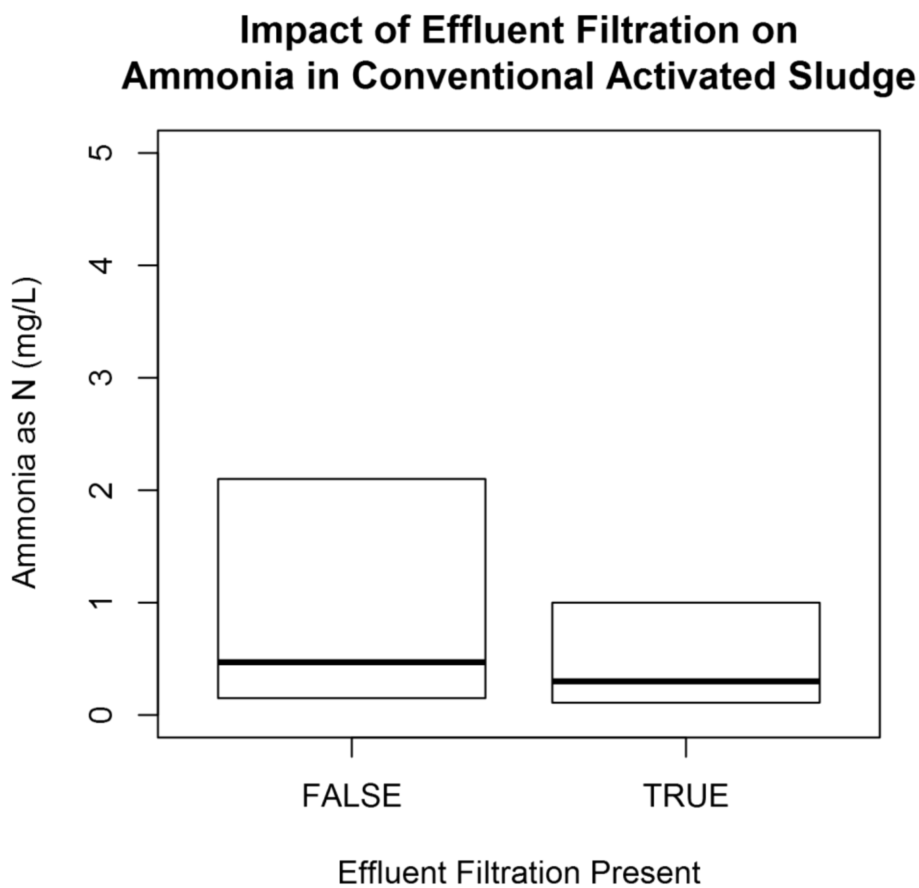


Table 13. Observations and Facility Count for Effluent Filtration in Conventional Activated Sludge

Effluent Filtration Present	n	Unique Facilities
True	508	16
False	1000	30

The presence of effluent filtration also demonstrated reduced effluent ammonia at Conventional Activated Sludge facilities, especially at the upper quartile. Since ammonia is typically understood to be a dissolved constituent, this benefit may accrue from the removal of particulate material, the breakdown of which could contribute to effluent ammonia.

Companion Interactive AEMR Web Application

A companion web application to this report was developed and posted via the R Studio © shinyapps.io portal. This application allows users to select secondary treatment type, analytical parameter, and other features to extract interquartile ranges and boxplots from the AEMR data. Because the web app facilitates actual data sub-setting and generates tables and plots in real-time, the range of possible evaluations far exceed what could be provided in a static written report although within the limited options of the app. This application can be found at:

https://johnyagecic.shinyapps.io/AEMRExplorerShinyApp/

Recommendations for Future Work

Representative air temperature values were attributed to each facility and month. This allows for the possibility of constructing a statistical model for estimating effluent concentrations based on air temperature (instead of month) along with the other treatment plant features. This may facilitate the usefulness of this data beyond the Delaware River Basin. It is anticipated that DRBC staff will investigate the feasibility of developing such a statistical model following completion of this report.

References

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