International Stormwater Best Management Practices (BMP) Database

BMP Performance Summary: Chesapeake Bay and Related Areas

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Disclaimer

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The BMP Database ("Database") was developed as an account of work sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (USEPA) (collectively, the "Sponsors"). The Database is intended to provide a consistent and scientifically defensible set of data on Best Management Practice ("BMP") designs and related performance. Although the individuals who completed the work on behalf of the Sponsors ("Project Team") made an extensive effort to assess the quality of the data entered for consistency and accuracy, the Database information and/or any analysis results are provided on an "AS-IS" basis and use of the Database, the data information, or any apparatus, method, or process disclosed in the Database is at the user's sole risk. The Sponsors and the Project Team disclaim all warranties and/or conditions of any kind, express or implied, including, but not limited to any warranties or conditions of title, non-infringement of a third party's intellectual property, merchantability, satisfactory quality, or fitness for a particular purpose. The Project Team does not warrant that the functions contained in the Database will meet the user's requirements or that the operation of the Database will be uninterrupted or error free, or that any defects in the Database will be corrected.

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The Project Team's tasks have not included, and will not include in the future, recommendations of one BMP type over another. However, the Project Team's tasks have included reporting on the performance characteristics of BMPs based upon the entered data and information in the Database, including peer reviewed performance assessment techniques. Use of this information by the public or private sector is beyond the Project Team's influence or control. The intended purpose of the Database is to provide a data exchange tool that permits characterization of BMPs solely upon their measured performance using consistent protocols for measurements and reporting information.

The Project Team does not endorse any BMP over another and any assessments of performance by others should not be interpreted or reported as the recommendations of the Project Team or the Sponsors.

Acknowledgements

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BMP PERFORMANCE SUMMARY: CHESAPEAKE BAY AND RELATED AREAS

1 INTRODUCTION

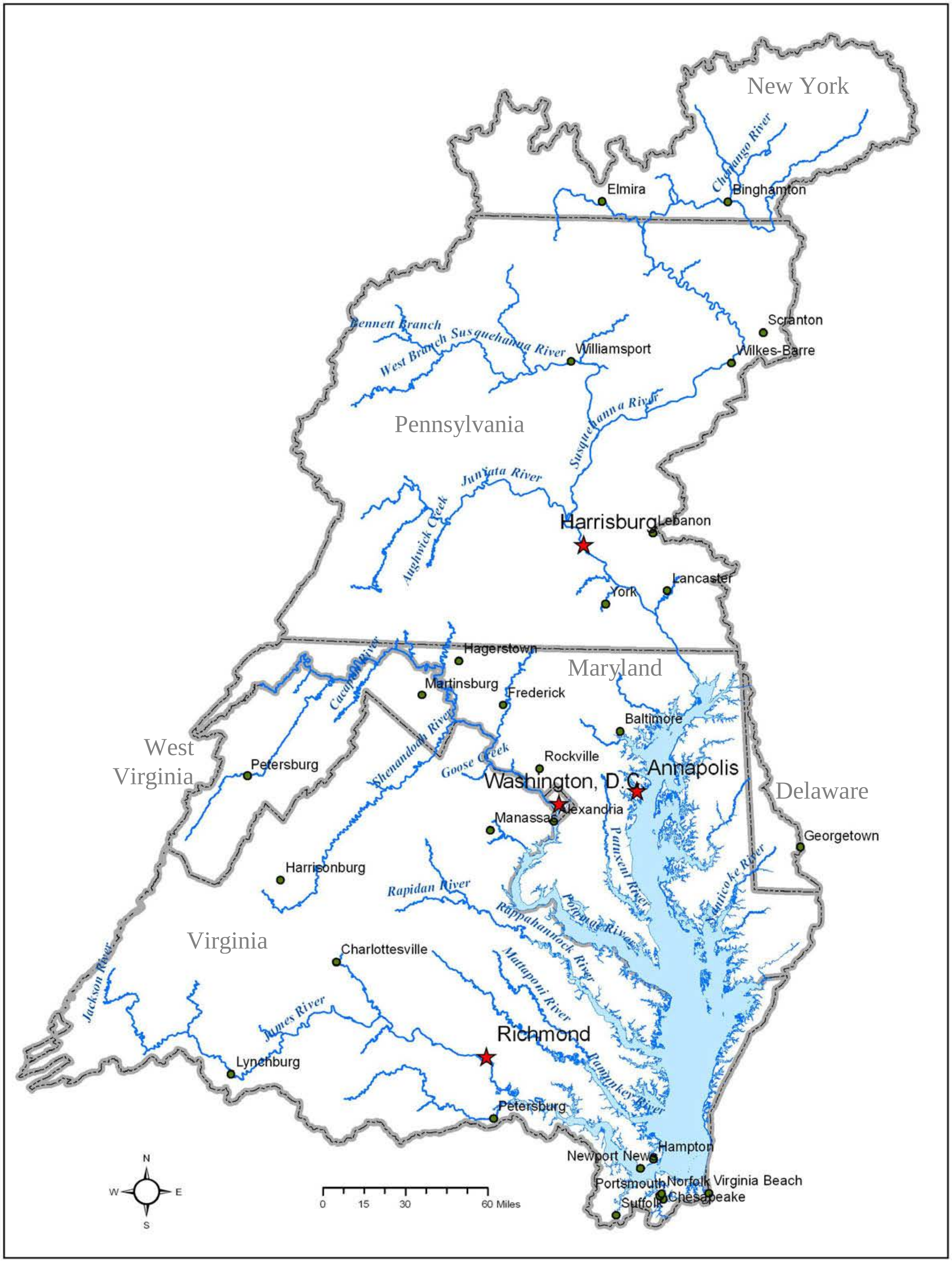
1.1 Background

The Chesapeake Bay (Bay) watershed drains an area of approximately 64,000 square miles including five major rivers (Susquehanna, Potomac, James, Rappahannock, and York) and parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) as well as the entire District of Columbia (Figure 1). The Bay is impaired by excessive algal growth, low dissolved oxygen, reduced water clarity, and declining aquatic life resources. In response to these impairments, the U.S. EPA issued the Bay Total Maximum Daily Load (TMDL) on December 29, 2010 to address high watershed loadings of nitrogen, phosphorus, and sediment (U.S. EPA, 2010). The TMDL calls for a 25 percent reduction in nitrogen, 24 percent reduction in phosphorus, and 20 percent reduction in sediment loads to the Bay and its tidal waters. While agricultural runoff is the largest contributor to pollutant loads, urban and suburban stormwater have been estimated to contribute about 20% of the total nutrient load to the Bay each year (Schueler, 2011). To meet the load reduction targets, the estimated reductions needed from urban and suburban runoff are approximately 35% for total nitrogen and 36% for total phosphorus.

Effective urban stormwater best management practices (BMPs) must be implemented to meet load reduction targets at the current and future levels of development in the Bay watershed. To support watershed planning efforts, stakeholders need access to the most current and complete information on the performance of BMPs. The International Stormwater BMP Database (www.bmpdatabase.org) is a publically-available database containing design, tributary watershed and performance data for over 500 BMPs in the U.S. and other countries, with many studies in and around Chesapeake Bay.

A targeted performance analysis of BMP Database (BMPDB) studies located in or near the Bay has been completed and is provided in this technical summary. As part of this effort, additional test sites and BMP studies located in or near the Bay watershed were identified and entered into the BMPDB. This expanded data set was used to provide a current summary and assessment of treatment effectiveness by BMP type for sediment, nitrogen, and phosphorus, as summarized in the remainder of this technical summary.

Figure 1. Chesapeake Bay Watershed (Source: U.S. EPA, 2010).



1.2 Purpose and Scope

The purpose of this technical summary is to provide scientifically sound information to Chesapeake Bay stakeholders regarding urban stormwater BMP performance to support effective urban stormwater management strategies in the Chesapeake Bay watershed. A set of "Chesapeake Bay-related" BMP studies (e.g., similar climate, soils, topography) located within the Chesapeake Bay watershed and surrounding areas has been analyzed using established statistical approaches, which have been presented in past work products (performance summaries and technical memoranda) for the BMPDB. Analysis results in this technical summary are presented as statistical performance summaries of influent and effluent event mean concentrations (EMCs) by BMP category. These results are compared to other BMP studies contained in the BMPDB excluding Chesapeake Bay-related studies (non-CBay) to assess whether influent water quality and BMP performance in the Chesapeake Bay-related studies (CBay) are significantly different from the remaining national data set for each constituent of concern. This comparison provides an indication of how factors such as climate, land use/land cover and BMP design characteristics unique to the Chesapeake Bay watershed may or may not influence BMP performance. Other factors such as study design and data quality and quantity may also impact the comparability of Chesapeake and non-Chesapeake Bay studies.

1.3 Typical Sources of Sediment and Nutrients

Sediment and nutrients are naturally present to varying degrees in surface waters and stormwater runoff. However, both urban and agricultural human activities can increase sediment and nutrient loads to levels that impact aquatic life and other beneficial uses of water bodies. Sources of sediment in urban runoff include construction activities, denuded landscape areas, eroding streams and channels, road sanding, decaying leaves or other organic matter (detritus), metallic dust from car brakes, tires, or engines, erosion of hillslopes, dust from atmospheric deposition (either directly deposited or carried by rain), and a variety of other human and natural sources. Accelerated stream channel erosion is common in urban (and agricultural) areas due to increased flow rates, durations and volumes from urban runoff, with the extent of erosion varying based on site-specific factors.

Nutrients are necessary for the health of aquatic ecosystems, but excessive nutrients can result in harmful algal blooms which can lead to oxygen depletion, aquatic species imbalances, public health threats, and general declines in aquatic resource values. Human activities associated with nutrient over-enrichment in water bodies include agricultural and urban/residential fertilization, treated sewage effluent, detergents, septic systems, combined sewer overflows, sediment mobilization, and animal waste. Human activities can also affect natural processes such as atmospheric deposition (e.g., fuel combustion resulting in NOx emissions), internal nutrient recycling from sediment, and stream channel erosion. Stream and channel erosion of soils with higher nutrient levels can also be a significant source.

Nutrient loading to receiving waters as a result of the above activities varies for each primary nutrient because of the unique chemical characteristics of each. Phosphorus, because of its tendency to sorb to soil particles and organic matter, is primarily transported in surface runoff with eroded sediments, but may also be significantly present as dissolved inorganic phosphate and organophosphate compounds. In urban and suburban rainfall-runoff, phosphorus sources include fertilizer use, detergents, flame-retardants in many applications (including lubricants), corrosion inhibitors, and plasticizers. In areas with high phosphorus content in soils, deposition of sediment due to construction or other land disturbance activities or stream channel erosion can also represent a significant source. Phosphorus can also be associated with fine-grained particulate matter found in the atmosphere which can enter natural waters through both dry fallout and rainfall.

Compared to phosphorus, nitrogen does not sorb strongly to soil particles and is transported in surface runoff in both particulate and dissolved phases. Dissolved inorganic nitrogen can be transported to surface waters through the unsaturated zone and groundwater. Because nitrogen species may occur as a gaseous phase in the environment, it can be transported to surface water via atmospheric deposition as well. The major sources of nitrogen in urban watersheds include sewage treatment plants, high-density animal operations, agriculture, applied fertilizers, and vehicle and industrial emissions. In some locations, dry weather flows associated with groundwater inflows (inflow into to urban stormwater systems) can also be a source of both phosphorous and nitrogen, particularly in areas of historic wetlands where highly organic soils may be present.

1.4 BMP Design Considerations

Dominant removal mechanisms for sediment and particulate-bound nutrients include volume reduction, sedimentation and filtration. The effectiveness of the last two processes can be enhanced by coagulation and flocculation. Sedimentation can effectively remove particles down to approximately 20 μm. However, in the absence of active coagulant dosing, stormwater filtration is typically needed to remove fine particles (<20 μm). Media filters, bioretention, disposable or rechargeable filter cartridges, or other infiltration-based BMPs provide filtration. For all of these facilities, regular maintenance is necessary to minimize clogging. The gradation and effective pore size of media beds relative to the target particle size should be carefully considered in design. A small effective pore size will remove small particles, but will also be more prone to clogging. Vegetation can be planted on the top of media beds and infiltration basins to help maintain flow-through rates by breaking up surface crusts and providing preferential flow paths along stems and roots. However, large trees and shrubs that generate large quantities of leaf litter may seal the surface of the filter and reduce infiltrative capacity and may also increase rehabilitation costs if tree and shrub removal/replacement is needed.

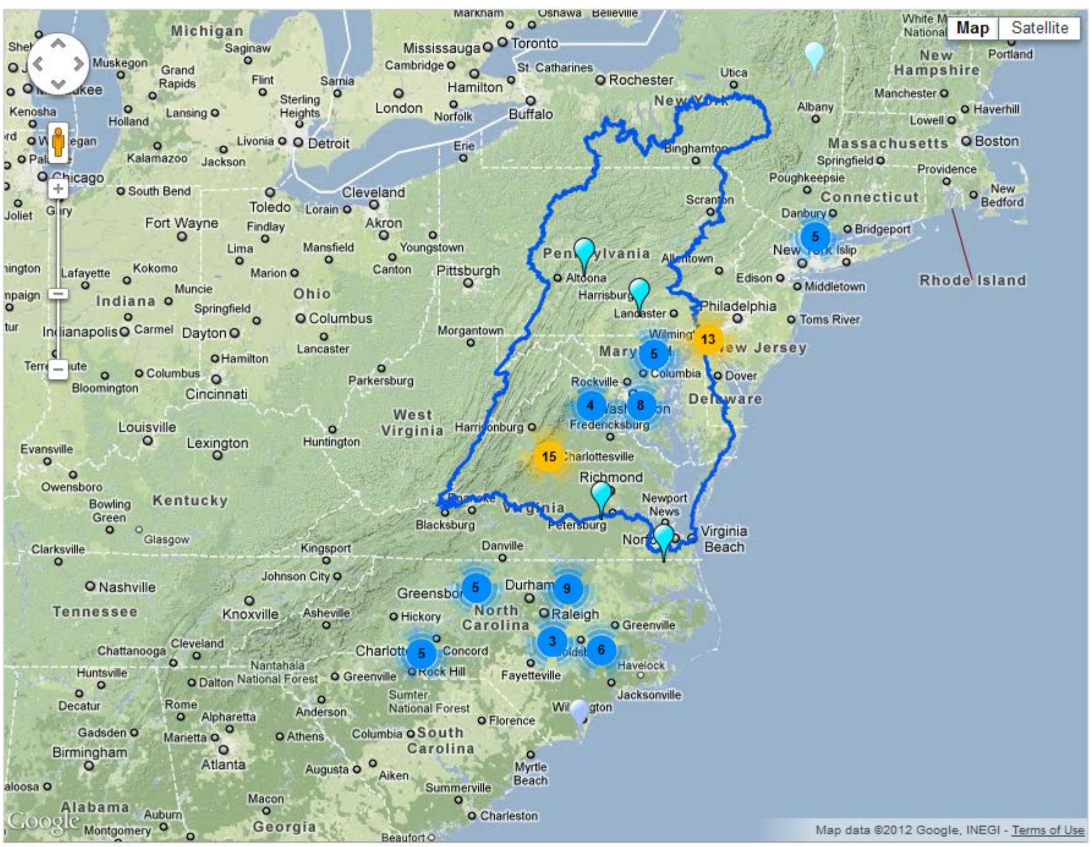
Filtration can also be an effective process for removal of phosphorus when media properties are suitable for sorption, precipitation, and complexation of soluble or dissolved phosphorus. Media or soils containing iron, aluminum, calcium, or hydrated Portland cement can be very effective at removing phosphorus species from solution through surface complexation or precipitation. However, complexation or partitioning to engineered media or particulate matter can be reversible and particulate-bound phosphorus can be a chronic threat, especially in a cyclic redox environment (WERF, 2005).

Nitrogen in stormwater runoff is predominantly organic nitrogen (e.g., leaves and other organic debris) and nitrate. For removal of organic nitrogen (which is predominantly particulate matter), BMPs that facilitate settling and filtration, as well as biological activity under aerobic conditions, will be the most effective. Conversely, for removal of nitrate (which is soluble), treatment processes conducive to biological activity under anaerobic conditions (e.g., surface or subsurface flow wetlands) will be most effective. Wetlands are ideal for nitrogen removal due to the variable depth zones that provide a diversity of oxidation-reduction potential conditions, and the shallow depths and long residence times that allow for microbial transformation processes to occur. Filtration processes are not expected to be effective for nitrate (Davis et al., 2006) except in special circumstances such as with engineered bioretention designed to incorporate a continuously submerged anoxic zone with an overdrain (Kim et al., 2003). Ammonia, which occurs at relatively low levels in typical urban runoff, would be effectively removed in wetlands and other long residence time treatment BMPs through volatilization and microbially-mediated oxidation/nitrification processes.

1.5 Inventory of Available Chesapeake Bay Data in the BMPDB

As mentioned above, the Chesapeake Bay watershed boundary includes portions of Virginia, West Virginia, Maryland, Delaware, Pennsylvania and New York. As shown in Table 1, the BMPDB contains a total of 67 BMP studies located in these states. To provide a larger and more robust data set, the Project Team included studies in these states (including some studies outside the physical watershed) and studies in North Carolina. The basis for inclusion of North Carolina studies is described further below. Figure 2 is a map shown the locations of the test sites with BMP studies included in the Chesapeake Bay data set. Note that the symbols on the map represent test sites, and some test sites may have multiple BMP studies.

Figure 2. Map Showing Locations Chesapeake Bay Test Sites Contained in the BMPDB.



(Note: An interactive version of this map is available at: http://www.bmpdatabase.org/MapCBay.html)

The Database contains approximately 50 BMP studies located in North Carolina, which is just south of the southernmost portions of the watershed. In addition to its geographic proximity to the Chesapeake Bay, this area also experiences relatively similar rainfall patterns and climate conditions based on defined rainfall or climate "zones" from several published sources. Driscoll et al. (1989) placed most of North Carolina in the "Mid-Atlantic" rain zone along with areas of Virginia, Maryland, Pennsylvania and Delaware – representing a large portion of the Chesapeake Bay watershed. This classification indicates that North Carolina has similar average annual rainfall characteristics to the Chesapeake Bay watershed (number of storms, intensity, duration, volume and storm separation). In addition, the National Climatic Data Center (NCDC) classifies North Carolina, along with Virginia, in the "Southeast" climate region based on historically consistent climate patterns. Further, in conducting literature reviews of existing BMP data for the development of BMP definitions and effectiveness estimates for the Chesapeake Bay watershed, Simpson and Weammert (2009) identified applicable studies as those conducted in "humid, temperate climates east of the Rockies." Finally, the soils in North Carolina are very similar to those in the southern part of the Chesapeake Bay watershed. The dominant soil order in this region is Ultisols, or red clay soils, that are characterized as strongly leached, acid soils where intense weathering of the primary minerals (Ca, Mg, K) has occurred (University of Idaho, n.d.).

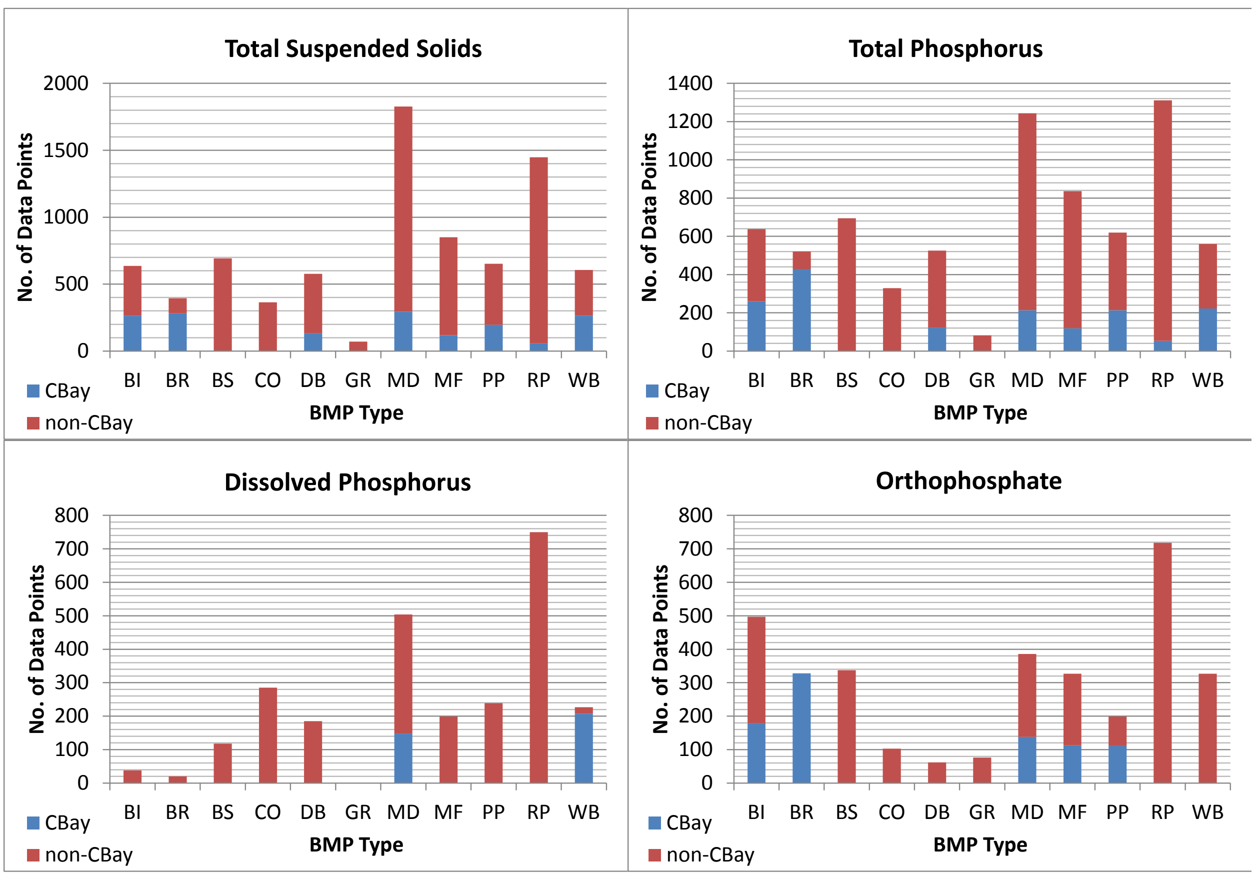
Based on a review of the studies discussed above, the North Carolina studies have been identified as appropriate for inclusion in the set of "Chesapeake-Bay related" studies considered in this analysis. These North Carolina studies add a substantial amount of data to the data set for the studies within the Chesapeake Bay watershed.

Table 1 summarizes BMP studies in the Chesapeake Bay-related (CBay) area including those in the watershed and states with conditions reasonably similar to those in the Chesapeake Bay area. Figure 3 summarizes the number of stormwater data points for these studies (CBay) as well as others in the database (non-CBay) for total suspended solids (TSS), total phosphorus (TP), dissolved phosphorus (DP), and orthophosphorus (OP). Figure 4 summarizes the number of data points for total nitrogen (TN), total Kjeldahl nitrogen (TKN), nitrite plus nitrate (NO2+NO3), nitrate (NO3), and ammonia (NH3). As shown, data are limited for bioswales, composite BMPs (BMPs in series), and green roofs. The most commonly reported nutrients are TP, OP, TKN, NO2+NO3, with limited data available for TN, NH4, NO2, NO3, and DP.

Table 1. "Chesapeake Bay-Related Area" Studies by State and BMP Category.

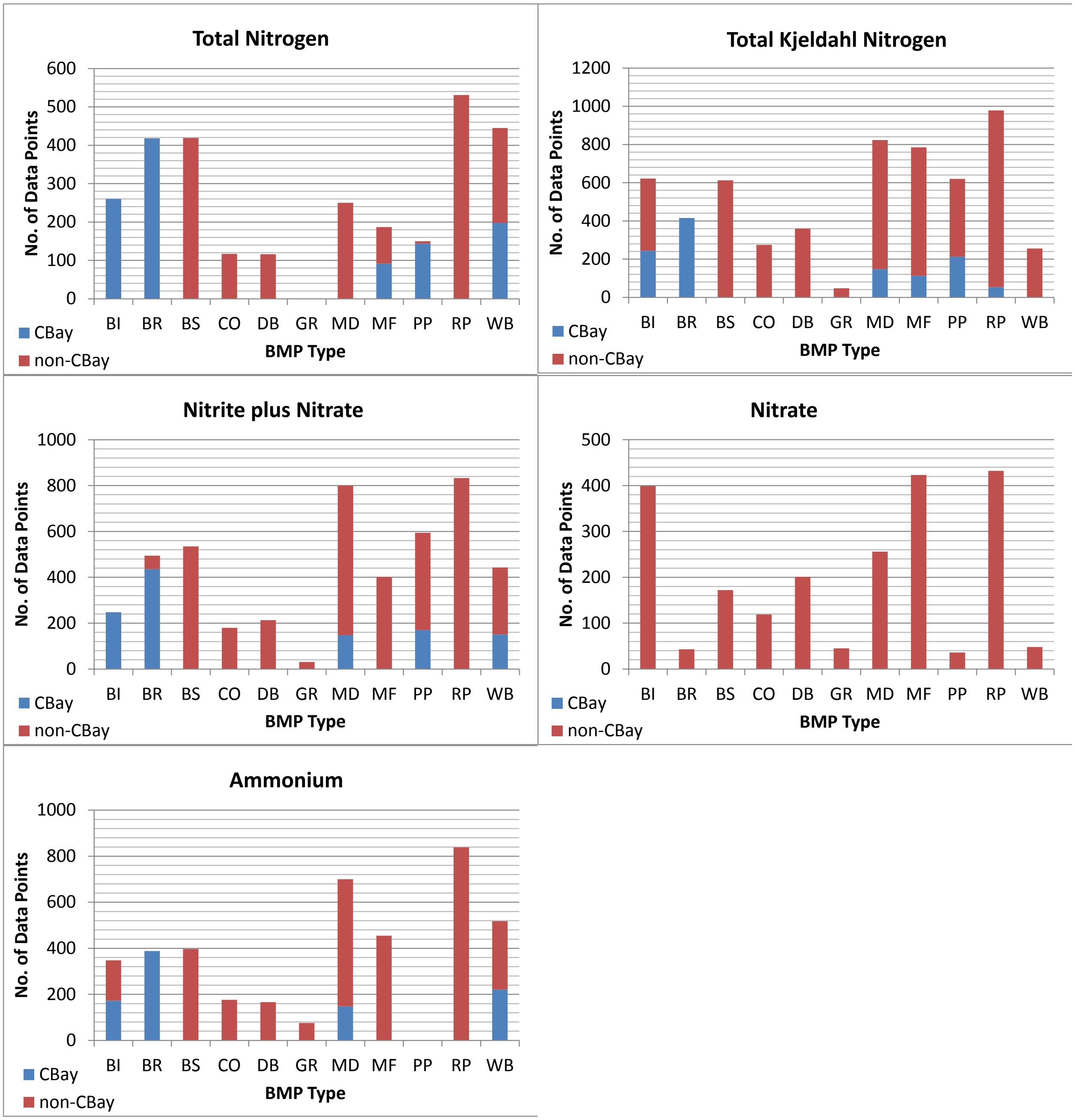
State	Grass Strip (BI)	Bioretention (BR)	Grass Swale (GS)	Composite (CO)	Detention Basin (DB)	Green Roof (GR)	Manufactured Device (BD)	Media Filter (MF)	Permeable Pavement (PP)	Retention Pond (RP)	Wetland Basin (WB)	Total
DE		1					7	1				9
MD					1		2	2			3	8
NY					4		1	1				6
PA		1				3	1		3			8
VA	1	3	10	1	6	1	6	1		1	6	36
NC	8	15	2	4	1				11	5	2	48
Total	9	20	12	5	12	4	17	5	14	6	11	115

Figure 3. Number of BMP Effluent EMCs for Chesapeake Bay Area: Total Suspended Solids, Total Phosphorus, Dissolved Phosphorus, and Orthophosphate.



Key for BMP Types: BI = Buffer Strip (grass filter strip), BR = Bioretention, BS = Bioswale; CO = Composite System; DB = Detention Basin (dry); GR = Green Roof; MD = Manufactured Device; PP = Permeable Pavement; RP = Retention Pond (wet); and WB = Wetland Basin.

Figure 4. Number of BMP Effluent EMCs for Chesapeake Bay Area: Total Nitrogen, Total Kjeldahl Nitrogen, Nitrite plus Nitrate, Nitrate, and Ammonium.



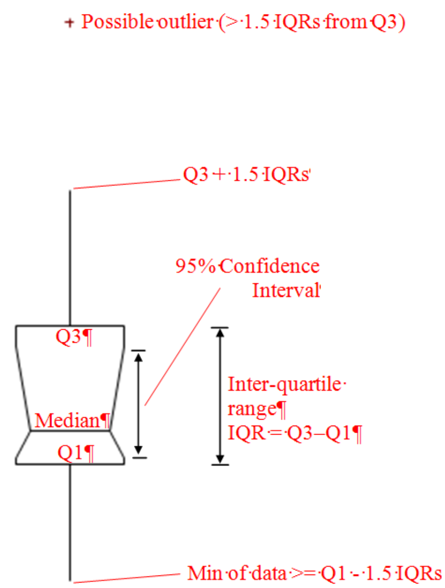
Key for BMP Types: BI = Buffer Strip (grass filter strip), BR = Bioretention, BS = Bioswale; CO = Composite System; DB = Detention Basin (dry); GR = Green Roof; MD = Manufactured Device; PP = Permeable Pavement; RP = Retention Pond (wet); and WB = Wetland Basin.

2 CATEGORY-LEVEL BMP ANALYSIS FOR CHESAPEAKE BAY STUDIES

An overview of BMP performance for TSS, phosphorus, and nitrogen is provided for the Chesapeake Bay area in the subsections below. The analysis focuses on the distribution of effluent water quality for individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of data points reported.

The BMP categories included in this analysis are filter strips, bioretention with underdrains, dry detention basins (surface/grass-lined), manufactured devices, media filters, porous pavement, retention ponds (surface pond with a permanent pool), and wetland basins (basin with open water surface). The effectiveness and range of unit treatment processes present in a particular BMP may vary depending on the BMP design. Several other BMP categories and sub-classes are included in the BMPDB, but these have been excluded from this analysis due to limited data sets available for meaningful categorical comparisons. BMP categories with less than three studies or individual studies with less than three data points are not included in this analysis.

Figure 5. Box Plot Key.



In the subsections below, side-by-side box plots for the various BMPs and constituents have been generated using the influent and effluent concentrations from the studies. For each BMP category, the influent box plots are provided on the left and the effluent box plots are provided on the right. A key to the box plots is provided in Figure 5.

In addition to the box plots, tables of influent/effluent medians, 25th and 75th percentiles, and number of studies and data points are provided, along with 95% confidence intervals about the medians. The median and interquartile ranges were selected as descriptive statistics for BMP performance because they are non-parametric (do not require distributional assumptions for the underlying data set) and are less affected by extreme values than means and standard deviations. Additionally, the median is less affected by assumptions regarding values below detection limits and varying detection limits for studies conducted by independent parties over many years. However, confidence intervals about the median can still be affected by outliers if simple substitution is used. Therefore, a robust regression-on-order statistics (ROS) method as described by Helsel and Cohn (1988) was utilized to provide probabilistic estimates of non-detects before computing descriptive statistics.

Confidence intervals in the figures (shown by "notches" in the boxplots) and tables were generated using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibshirani (1993). This method is a robust approach for computing confidence intervals that is resistant to outliers and does not require any restrictive distributional assumptions. Following guidance by McGill et al. (1978): "The notches surrounding the medians provide a measure of the rough significance of differences between the values. Specifically, if the notches about two medians do not overlap in this display, the medians are, roughly, significantly different at about a 95% confidence level." Given the broad nature of the analysis contained in this paper, these general comparisons of differences are considered adequate; however, more robust hypothesis testing has also been provided in Attachment 1. Specifically, the Mann-

Whitney test for independent data sets (unpaired samples) and the Wilcoxon signed rank test (using log-transformed data) for paired inflow-outflow data have been provided (Helsel and Hirsch, 1992). Results of these tests are provided in the attached statistical summary reports for TSS and nutrients.

To identify the strength of the statistical differences as determined from comparisons of 1) confidence intervals about the medians, 2) results from the Mann-Whitney test, and 3) results from the Wilcoxon test, a key has been developed for use in summary tables below. A solid square next to a BMP type is used to indicate differences for each comparison method and an empty square is used to indicate the differences are not significant. The key to this symbology is as follows:

- ▪▪▪ 95% confidence intervals for the medians *do not overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *less* than 0.05.
- ▫▪▪ 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *less* than 0.05.
- ▫▪▫ 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *less* than 0.05, Wilcoxon test has a p-value *greater* than 0.05.
- ▫▫▪ 95% confidence intervals for the medians *overlap*, Mann-Whitney test has a p-value *greater* than 0.05, Wilcoxon test has a p-value *less* than 0.05.

The solid squares are also colored to indicate whether the effluent median may be higher than the influent. If the square is green, then the effluent median is less than the influent median and if the square is red, the effluent median is greater than the influent median. Be aware that for some BMP types, a statistically significant difference between influent and effluent concentrations may not be present, but the effluent concentrations achieved by the BMP are relatively low and may be comparable to the performance of other BMPs that have statistically significant differences between inflow and outflow. For example, data sets that have low influent concentrations and similarly low effluent concentration (i.e., clean water in = clean water out) may not show statistically significant differences.

Attachments 1 and 2 to this memorandum are statistical data analysis reports for sediment and nutrients, organized by BMP type. The reports contain additional summary statistics (e.g., mean, median, standard deviation, skewness, and 25th and 75th percentiles) and hypothesis test results. Influent/effluent box plots and probability plots are also presented in the attachments. Although the narrative of this report presents the median for purposes of category-level performance evaluations, other researchers may choose to evaluate and utilize other statistical measures provided in attachments, depending on the purpose of the analysis.

2.1 Total Suspended Solids

Eight BMP categories had sufficient data for statistical analysis for the Chesapeake Bay area data set. Figure 6 contains box plots of influent and effluent TSS concentrations for each BMP category. Table 2 summarizes the non-parametric summary statistics for TSS. All BMP categories except for porous pavement show statistically significant reductions in TSS concentrations. However, note that median influent and effluent concentrations for the porous pavement studies are lower than any of the other BMPs shown. Also, per the influent vs.

effluent plot for porous pavement in Attachment 1, concentration reductions appear to be occurring when influent concentrations are above approximately 10 mg/L. Effluent concentrations for porous pavement are similar to bioretention and media filters where the primary treatment mechanism is filtration. Wetland basins and retention ponds, both of which have permanent pools, perform well, with median effluent concentrations of 15 and 12 mg/L, respectively. Filter strips, extended detention basins, and manufactured devices have somewhat higher median effluent concentrations in the 20 to 25 mg/L range.

Figure 6. Box Plots of Influent/Effluent TSS Concentrations by BMP Type.

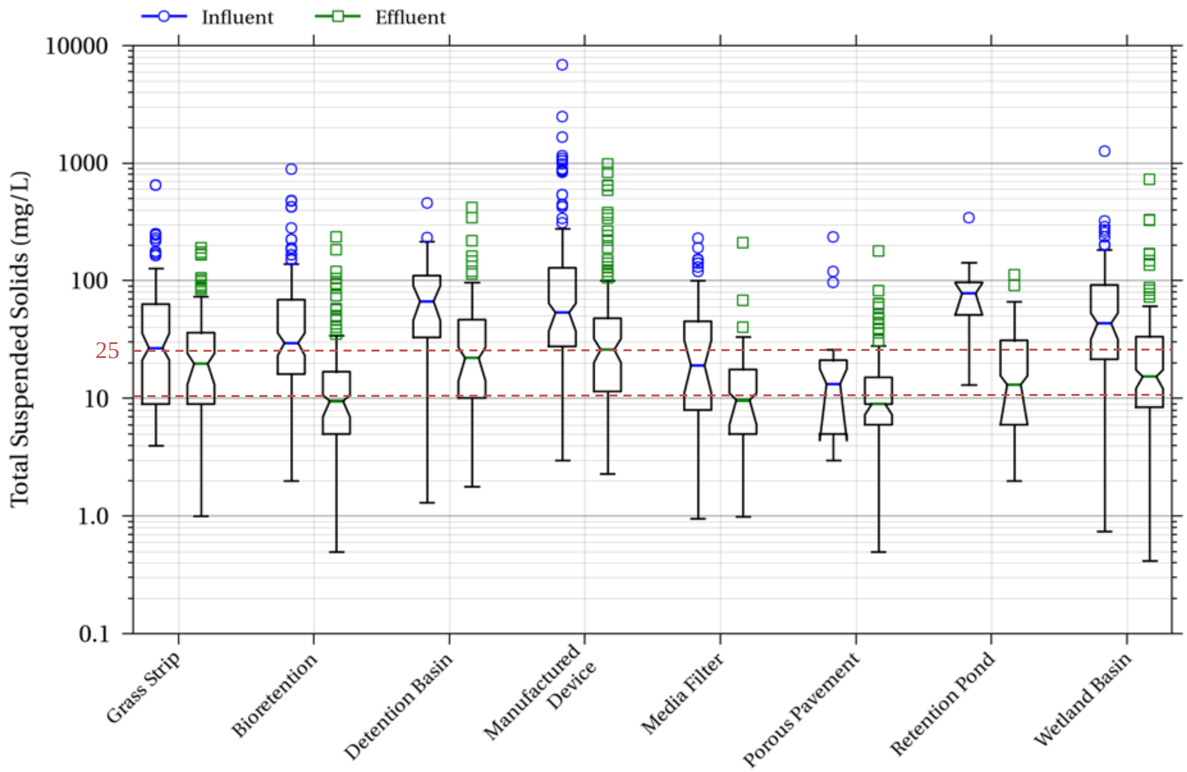


Table 2. Influent/Effluent Summary Statistics for TSS.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	8, 140	8, 123	9.0	9.0	26.7 (21.0, 35.5)	19.5 (13.0, 24.0)	63.0	36.0
Bioretention	11, 144	11, 138	16.0	5.0	29.5 (23.0, 36.0)	9.4 (7.0, 10.6)	68.8	16.8
Detention Basin	6, 55	7, 79	32.8	10.0	66.7 (45.6, 90.2)	21.8 (14.0, 27.0)	110.3	46.5
Manufactured Device	14, 147	14, 146	27.5	11.4	53.4 (37.0, 64.0)	25.8 (20.5, 32.0)	128.4	47.8
Media Filter	4, 57	5, 62	8.0	5.0	18.9 (11.0, 31.0)	9.7 (6.0, 11.0)	45.0	17.5
Porous Pavement	5, 49	10, 147	5.00	6.0	13.1 (6.0, 17.7)	9.0 (7.7, 9.0)	21.0	15.0
Retention Pond	4, 24	4, 34	51.0	6.0	77.8 (51.0, 95.0)	13.03 (6.5, 15.5)	96.5	31.0
Wetland Basin	7, 132	7, 132	21.4	8.5	43.2 (31.5, 52.9)	15.21 (12.0, 17.3)	91.8	33.3

2.2 Total Phosphorus

Figure 7 includes box plots of influent and effluent concentrations for total phosphorus for various BMP types for the CBay area, and summarizes the non-parametric summary statistics. As shown in the figure and table, detention basins, media filters, retention ponds, and wetland basins all appear to reduce median total phosphorus concentrations. Manufactured devices also appear capable of removing total phosphorus, but not consistently below about 0.16 mg/L. Grass strips show a tendency to increase total phosphorus; however with a paired influent/effluent analysis this increase is not significant at the 95% confidence level. Also, some of the influent/effluent data pairs for bioretention plotted in Attachment 2 indicate that export of phosphorus may occur, particularly when influent concentrations are low. Media filters, retention ponds and wetland basins tend to achieve the most dramatic decreases in total phosphorus with median effluent concentrations around 0.1 mg/L.

Figure 7. Box Plots of Influent/Effluent Total Phosphorus Concentrations by BMP Type.

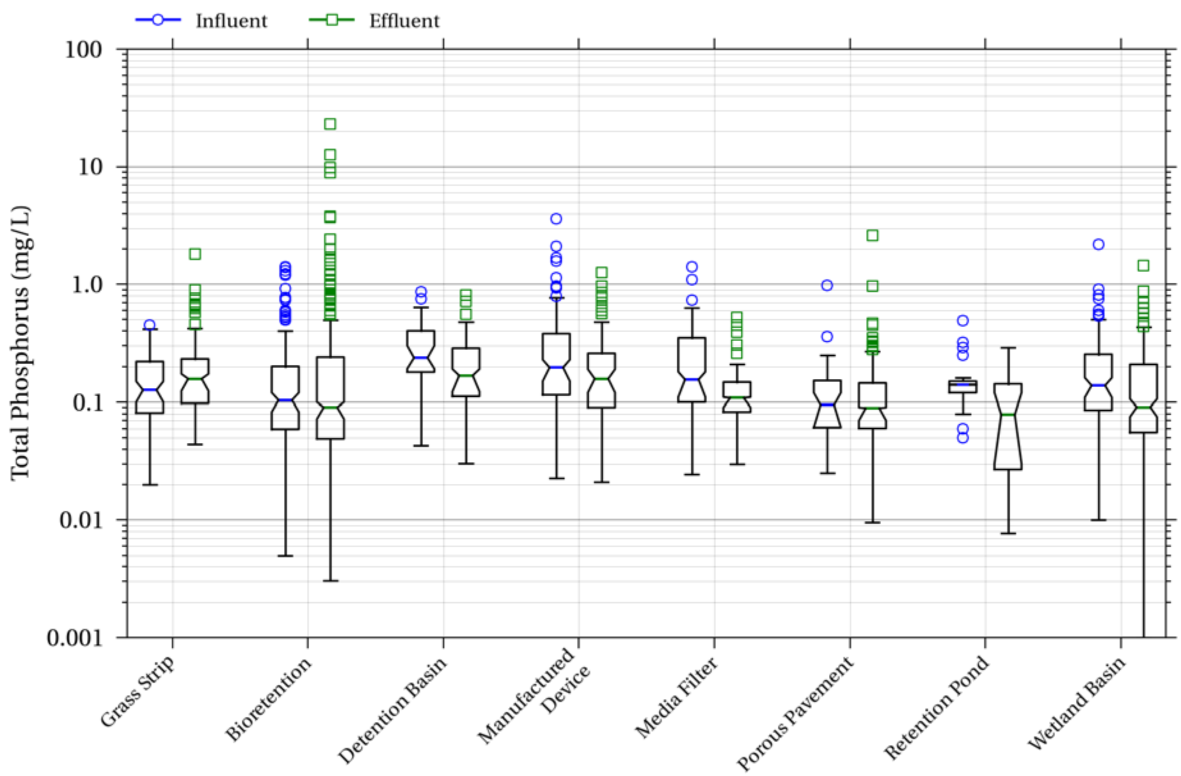


Table 3. Influent/Effluent Summary Statistics for Total Phosphorus.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	8, 138	8, 122	0.08	0.10	0.13 (0.10, 0.15)	0.16 (0.12, 0.17)	0.22	0.23
Bioretention	15, 224	15, 205	0.06	0.05	0.10 (0.08, 0.12)	0.09 (0.07, 0.10)	0.20	0.24
Detention Basin	6, 55	6, 67	0.18	0.11	0.24 (0.19, 0.30)	0.17 (0.12, 0.19)	0.40	0.29
Manufactured Device	11, 107	11, 106	0.11	0.09	0.20 (0.15, 0.23)	0.16 (0.12, 0.19)	0.38	0.26
Media Filter	4, 57	5, 62	0.10	0.08	0.16 (0.11, 0.18)	0.11 (0.09, 0.11)	0.35	0.15
Porous Pavement	5, 50	11, 163	0.06	0.06	0.09 (0.06, 0.12)	0.09 (0.07, 0.09)	0.15	0.15
Retention Pond	3, 21	4, 32	0.12	0.03	0.14 (0.14, 0.14)	0.08 (0.03, 0.12)	0.15	0.14
Wetland Basin	4, 111	4, 112	0.09	0.06	0.14 (0.11, 0.16)	0.09 (0.07, 0.11)	0.25	0.21

2.3 Dissolved Phosphorus

Categorical BMP summaries for DP are provided in Figure 8 and Table 4. As shown in the table, the Database only includes enough data for manufactured devices and wetland basins for statistical analysis of DP. As shown in the figure and table, manufactured devices do not show significant removals, but wetland basins are capable of reducing median effluent concentrations of DP to 0.04 mg/L.

Figure 8. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations by BMP Type.

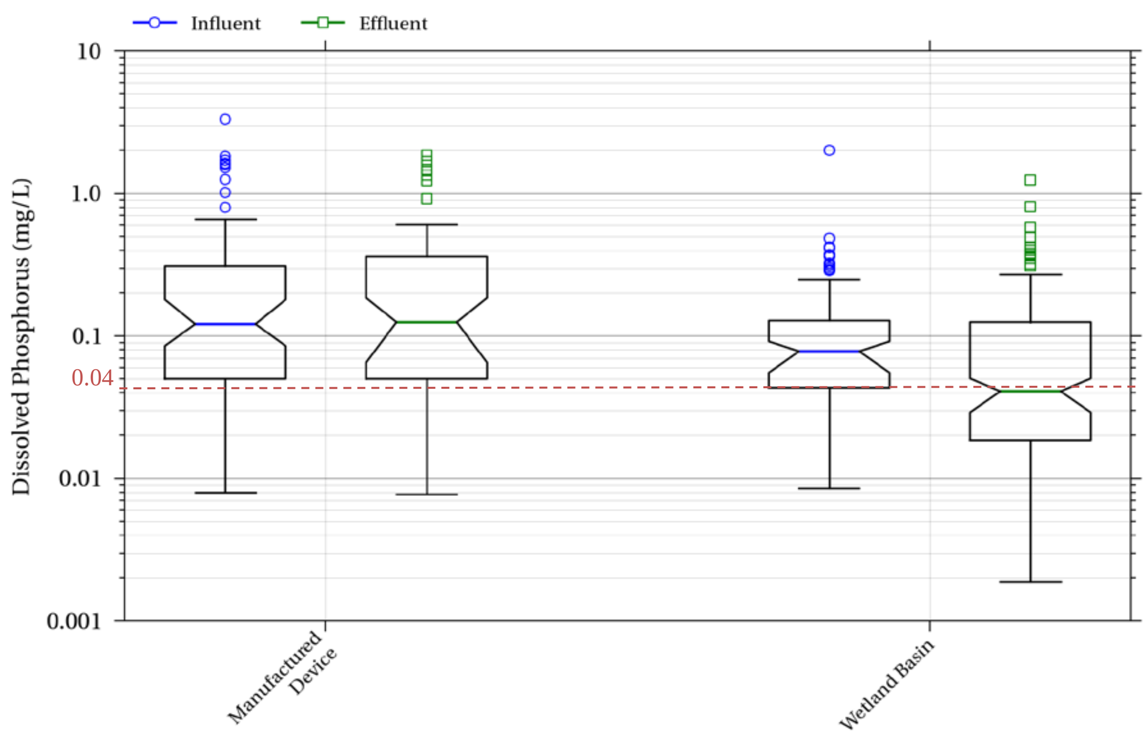


Table 4. Influent/Effluent Summary Statistics for Dissolved Phosphorus.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Manufactured Device ▫▫▫	7, 74	7, 74	0.05	0.05	0.12 (0.08, 0.18)	0.13 (0.06, 0.19)	0.31	0.36
Wetland Basin ▪▪▪	4, 104	4, 103	0.04	0.02	0.08 (0.06, 0.09)	0.04 (0.03, 0.05)	0.13	0.12

2.4 Orthophosphate

Categorical BMP summaries for OP are provided in Figure 9 and Table 5. As indicated, only media filters show strong statistically significant removals. Similar to TP, grass strips and bioretention tend to increase median OP concentrations. However, studies in both of these categories had very low influent concentrations. When considered at an overall category level, conclusions regarding performance of manufactured devices for OP are unclear (Mann-Whitney p-value = 0.256; Wilcoxon p-value = 0.001). Subcategories of manufactured devices that include adsorptive media may be more effective at reducing orthophosphate concentrations than the overall manufactured device category.

Figure 9. Box Plots of Influent/Effluent Orthophosphate Concentrations by BMP Type.

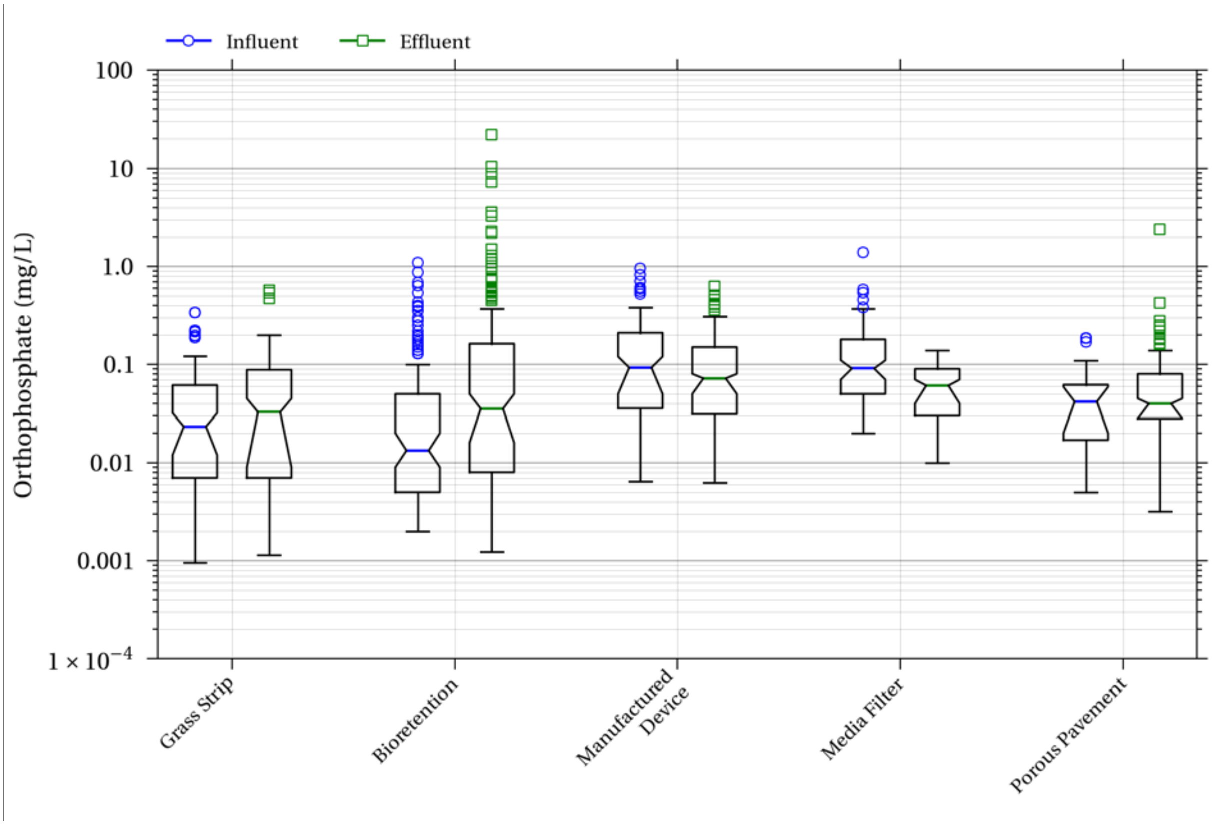


Table 5. Influent/Effluent Summary Statistics for Orthophosphate.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	5, 90	5, 89	0.01	0.01	0.02 (0.01, 0.03)	0.03 (0.01, 0.05)	0.06	0.09
Bioretention	13, 164	13, 164	0.00	0.01	0.01 (0.01, 0.02)	0.04 (0.02, 0.05)	0.05	0.16
Manufactured Device	7, 69	7, 69	0.04	0.03	0.09 (0.05, 0.12)	0.07 (0.05, 0.08)	0.21	0.15
Media Filter	4, 57	4, 56	0.05	0.03	0.09 (0.07, 0.11)	0.06 (0.04, 0.07)	0.18	0.09
Porous Pavement	5, 42	7, 69	0.02	0.03	0.04 (0.02, 0.06)	0.04 (0.03, 0.05)	0.06	0.08

2.5 Total Nitrogen

Figure 10 includes box plots of influent and effluent concentrations for total nitrogen for various BMP types and Table 6 summarizes the non-parametric summary statistics. As indicated in the figure and table, there are limited data available for total nitrogen. While bioretention is the only BMP with clearly statistically significant removals (per all three metrics), most BMPs indicate some reductions in total nitrogen (particularly wetland basins and potentially grass strips and media filters). Nitrogen releases from BMPs may occur seasonally as vegetation dies off. The seasonal characteristics of BMP performance is an area of needed research, especially in areas such as Chesapeake Bay where storm events frequently occur during all seasons of the year.

Figure 10. Box Plots of Influent/Effluent Total Nitrogen Concentrations by BMP Type.

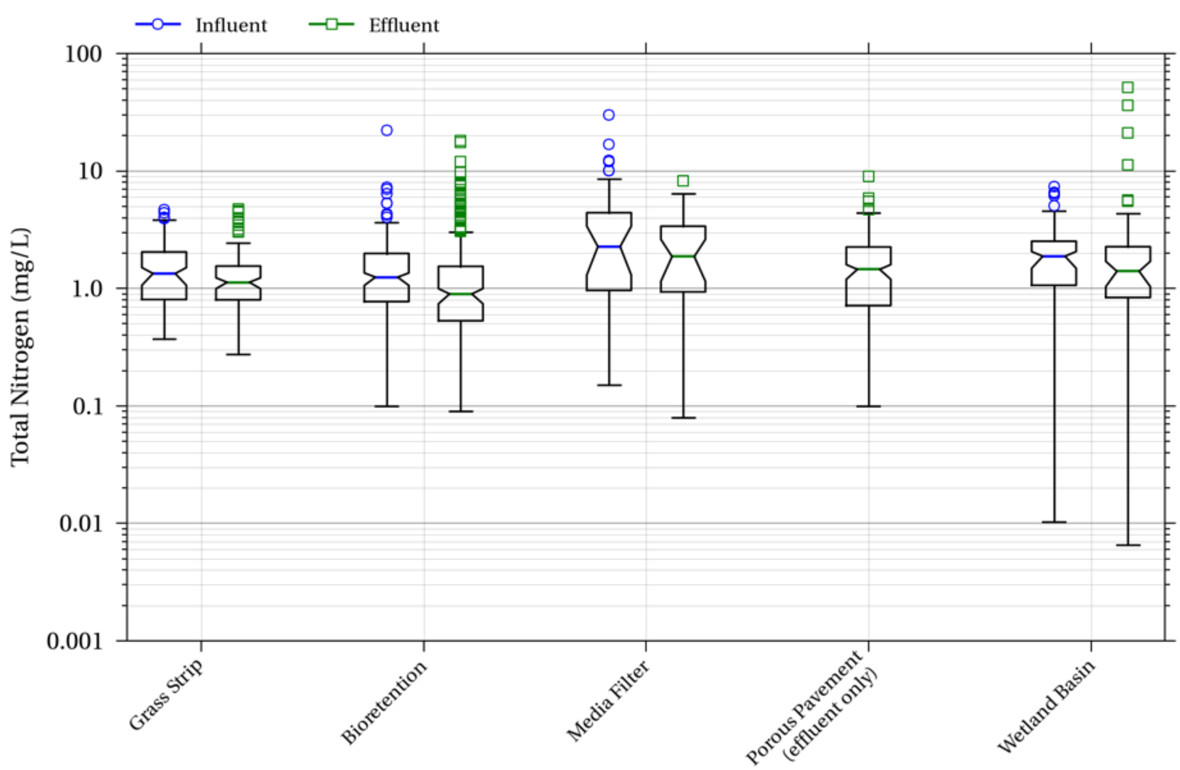


Table 6. Influent/Effluent Summary Statistics for Total Nitrogen.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip □□■	8, 138	8, 122	0.80	0.80	1.34 (1.05, 1.50)	1.13 (1.00, 1.23)	2.04	1.55
Bioretention ■■■	12, 218	12, 200	0.77	0.53	1.25 (1.06, 1.35)	0.90 (0.74, 0.99)	1.99	1.54
Media Filter □□■	3, 46	3, 46	0.96	0.94	2.27 (1.30, 3.39)	1.87 (1.15, 2.55)	4.41	3.39
Porous Pavement	NA	7, 130	NA	0.71	NA	1.45 (1.23, 1.60)	NA	2.25
Wetland Basin □■■	3, 98	3, 100	1.06	0.84	1.88 (1.48, 2.06)	1.40 (1.03, 1.70)	2.52	2.27

2.6 Total Kjeldahl Nitrogen

Figure 11 and Table 7 summarize influent and effluent statistics for total Kjeldahl nitrogen (TKN) for various BMP types. As indicated, most BMP types (except filter strips) provide some TKN reductions, but only bioretention and retention ponds appear to provide consistent, statistically significant removals for a wide range of influent concentrations (see Attachment 1). Manufactured devices, media filters, and porous pavement show statistically significant reductions for paired data per the Wilcoxon signed-rank test. When influent TKN concentrations are above 1 mg/L, media filters show reductions in TKN; at lower influent concentrations, results are less clear (partly explaining the Mann-Whitney p-value of 0.136). The influent concentrations for the porous pavement studies in the Chesapeake Bay area are much lower than the other BMP types (75th percentile influent TKN concentration is 1 mg/L). Statistically significant removals may occur for porous pavement at higher influent concentrations.

Figure 11. Box Plots of Influent/Effluent Total Kjeldahl Nitrogen Concentrations by BMP Type.

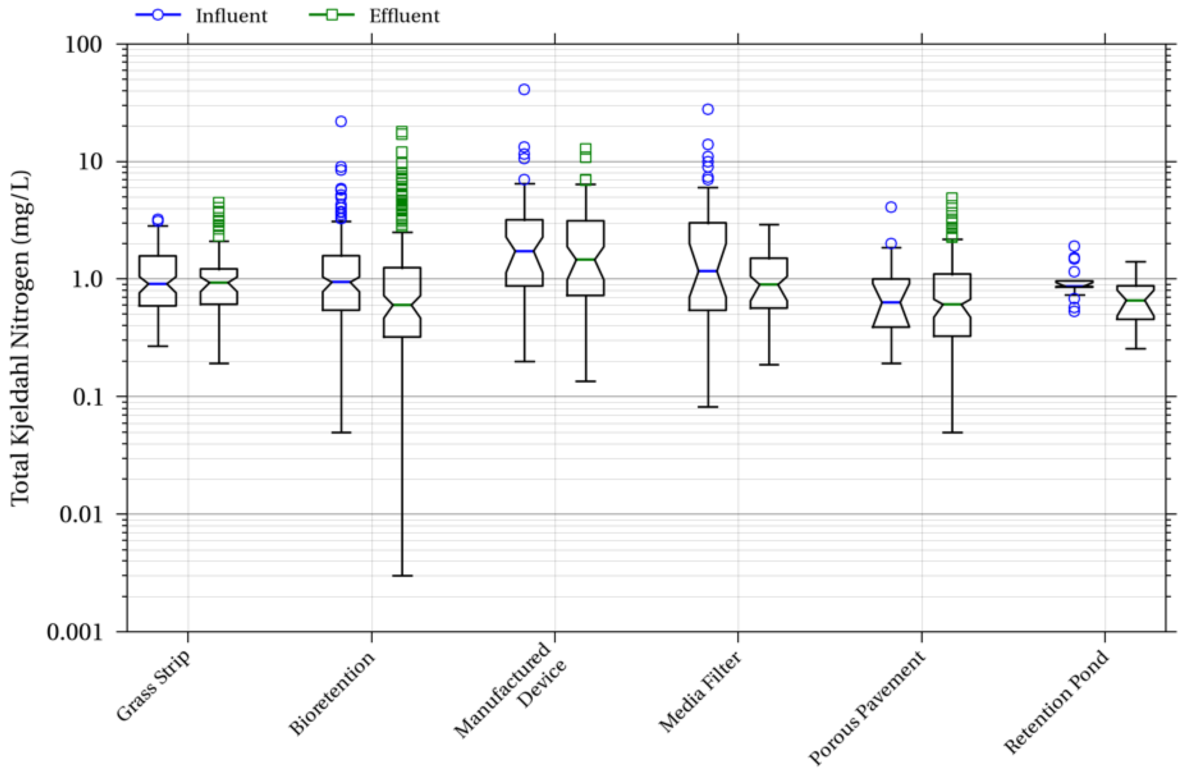


Table 7. Influent/Effluent Summary Statistics for Total Kjeldahl Nitrogen.

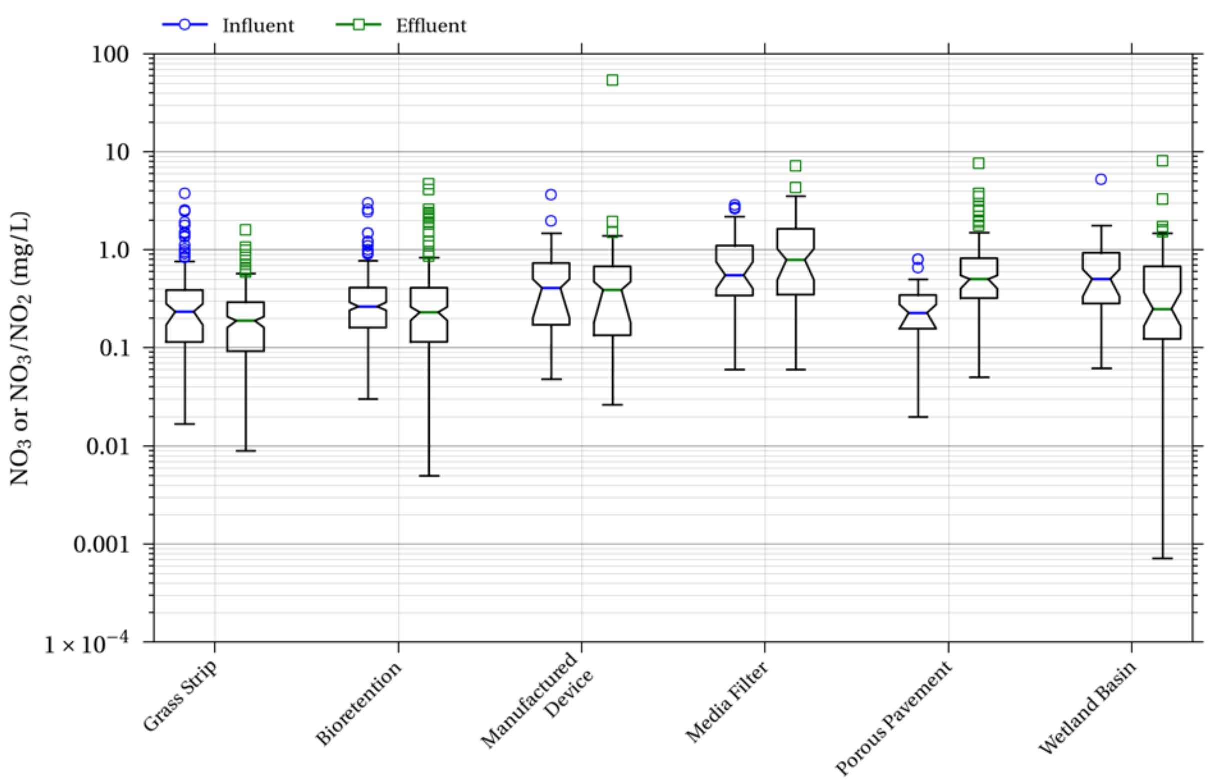
BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip □□□	7, 130	7, 114	0.59	0.61	0.91 (0.77, 1.05)	0.93 (0.77, 1.04)	1.57	1.22
Bioretention ■■■	14, 214	14, 201	0.54	0.32	0.94 (0.77, 1.04)	0.60 (0.46, 0.72)	1.58	1.25
Manufactured Device □□■	7, 74	7, 74	0.87	0.72	1.72 (1.11, 2.27)	1.46 (0.97, 1.87)	3.19	3.12
Media Filter □□■	4, 57	4, 56	0.54	0.56	1.16 (0.70, 2.00)	0.89 (0.70, 1.05)	3.00	1.50
Porous Pavement □□■	5, 50	11, 163	0.39	0.33	0.63 (0.39, 0.91)	0.61 (0.47, 0.67)	1.00	1.10
Retention Pond ■■■	3, 21	4, 32	0.85	0.45	0.86 (0.86, 0.93)	0.66 (0.48, 0.80)	0.96	0.87

2.7 Nitrate or Nitrite plus Nitrate

Nitrate (NO3) is typically the major component of nitrite plus nitrate (NO2+NO3) in stormwater and many studies either report NO2+NO3 or NO3, but not both. For these reasons, these two reported constituents have been combined prior to statistical analysis to provide a more robust (larger) data set than analyzing them separately.

Categorical BMP summaries for NO2+NO3 or NO3 (collectively referenced as NOx) are provided in Figure 12 and Table 8. As shown in the table, no BMP appears to provide consistent, statistically significant removals of NOx. Of the BMPs with available data, grass strips, bioretention and wetland basins are the most promising, but all of these have some events where the effluent concentration is higher, indicating export occurs. Effluent NOx concentrations for grass strips tend to be more strongly related to influent concentrations than for bioretention and wetland basins. These latter systems likely have anaerobic zones or cyclic redox environments that can provide the denitrification processes necessary for removing NOx species. The porous pavement studies indicate a statistically significant increase in NOx. The cause of this increase is unknown, but could be due to nitrification of decomposing organic matter that gets trapped in the pavement pore space or due to unrepresentative reference drainage areas.[2] Additional research is needed to fully evaluate these observations.

Figure 12. Box Plots of Influent/Effluent NOx Concentrations by BMP Type.



[2] Because sampling of the influent to porous pavement is often infeasible, reference drainage areas are typically sampled instead; these samples are considered representative of the influent to the porous pavement.

Table 8. Influent/Effluent Summary Statistics for NOx.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	8, 139	8, 123	0.11	0.09	0.23 (0.17, 0.29)	0.19 (0.16, 0.21)	0.39	0.29
Bioretention	15, 249	15, 230	0.16	0.11	0.26 (0.24, 0.29)	0.23 (0.19, 0.26)	0.41	0.41
Manufactured Device	7, 74	7, 74	0.17	0.13	0.41 (0.22, 0.50)	0.39 (0.17, 0.47)	0.73	0.68
Media Filter	4, 57	4, 56	0.34	0.35	0.55 (0.40, 0.75)	0.79 (0.47, 1.02)	1.10	1.63
Porous Pavement	5, 42	11, 158	0.16	0.32	0.23 (0.16, 0.28)	0.50 (0.40, 0.55)	0.34	0.82
Wetland Basin	3, 72	3, 79	0.28	0.12	0.50 (0.33, 0.63)	0.25 (0.17, 0.37)	0.93	0.67

2.8 Ammonia

Figure 13 includes box plots of influent and effluent concentrations for total ammonia for various BMP types and Table 9 summarizes the non-parametric summary statistics. As indicated in the figure and table, there is limited BMP data available for ammonia. Bioretention and wetland basins show significant reductions in ammonia concentrations. Grass strips and manufactured devices do not appear to be effective at reducing ammonia nitrogen. Clearly, additional data are needed for other BMP types to better understand which BMPs can be selected to address ammonia in stormwater runoff to Chesapeake Bay.

Figure 13. Box Plots of Influent/Effluent Ammonia Concentrations by BMP Type.

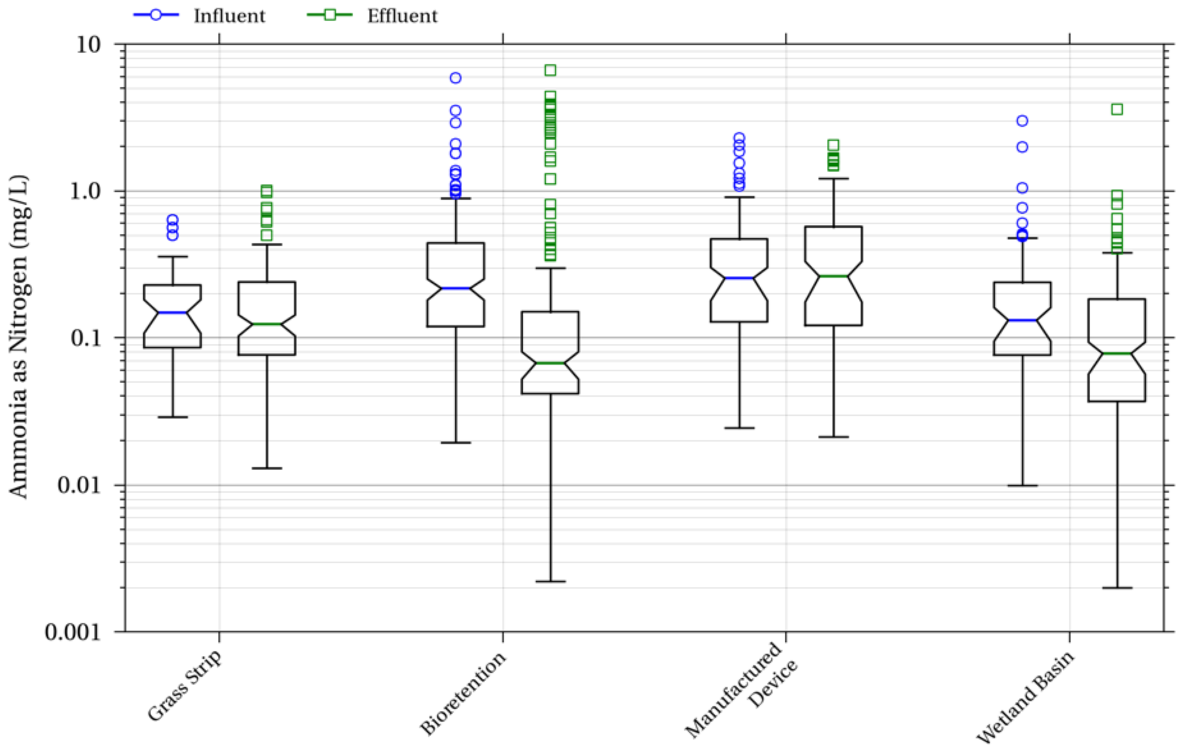


Table 9. Influent/Effluent Summary Statistics for Ammonia.

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	5, 87	5, 86	0.09	0.08	0.15 (0.11, 0.18)	0.12 (0.10, 0.14)	0.23	0.24
Bioretention	12, 204	12, 184	0.12	0.04	0.22 (0.18, 0.25)	0.07 (0.05, 0.08)	0.44	0.15
Manufactured Device	7, 74	7, 74	0.13	0.12	0.25 (0.18, 0.30)	0.26 (0.17, 0.33)	0.47	0.57
Wetland Basin	4, 111	4, 110	0.08	0.04	0.13 (0.09, 0.16)	0.08 (0.06, 0.09)	0.24	0.18

3 GENERAL BMP PERFORMANCE TRENDS AND COMPARISON TO NATIONAL DATA SET

Section 2 of this report focused on statistical analysis results for BMP studies in the Chesapeake Bay area, as contained in the BMPDB. Section 3 compares Chesapeake Bay area results to non-Chesapeake Bay area results in the BMPDB, as well as to load reduction estimates for the Chesapeake Bay area summarized by Schueler (2011).

3.1 Summary and Comparison to Non-Chesapeake Bay Studies

Table 10 summarizes the median influent concentrations for the Chesapeake Bay (CBay) and non-Chesapeake Bay (Non-CBay) studies and Table 11 summarizes the median effluent concentrations for each. The Mann-Whitney non-parametric hypothesis test was used to evaluate statistically significant differences between CBay and non-CBay studies. Statistically significant differences at the 95% confidence level are color coded green if CBay median is lower and red if CBay median is greater. Yellow indicates no significant difference and blank cells indicate insufficient data for comparison.

As shown in Table 10, the median influent concentrations are lower for many constituents for the CBay studies. Exceptions include TSS and DP for manufactured devices, OP and NOx for media filters, and all constituents for wetland basins. This comparison indicates that influent loading characteristics for the CBay studies may significantly differ from other studies in the database, which may be due to better source control, pretreatment before influent sampling, differences in soil characteristics, or general trends related to hydrology/runoff quality relationships (e.g., differences in build-up/wash-off functions).

There is also a general trend that if the median influent is lower for CBay studies, then the median effluent is also lower (or no difference), and vice versa. An exception is TP for bioretention where the median CBay influent is lower (0.10 mg/L vs. 0.16 mg/L), but the median CBay effluent is slightly higher (0.09 mg/L vs. 0.07 mg/L). Several factors could contribute to this observation, such as differences in media mix design, dominant phosphorus species present in runoff, hydraulic loading rates, study design and quality control. The high removal of TSS for CBay bioretention studies may indicate that a lower percentage of total phosphorus is associated with particulates than for non-CBay bioretention studies; however, the current data set is too limited to draw a robust conclusion.

Comparing effluent concentrations in Table 11, it is interesting to note that several of the BMP categories have comparable performance inside and outside of CBay, particularly for TSS. For example, grass strips and detention basins each perform similarly with effluent concentrations between 20 and 25 mg/L. Media filters and retention ponds have TSS effluent concentrations between 8 and 13 mg/L regardless of whether they are in the Bay region or not. Grass strips tend to show lower nutrient effluent concentrations for the CBay studies; however, statistically significant removals were only found for NOx (Section 2). Phosphorus concentrations tended to increase for grass strips in the CBay data set.

Table 10. Median Influent Concentrations for CBay/Non-CBay Studies.

	TSS	TP	DP	OP	NOx	TKN	NH3
Grass Strip	**26.7/51.1**	0.13/0.15		**0.02/0.04**	**0.23/0.64**	**0.91/1.50**	**0.15/0.41**
Bioretention	**29.5/68.7**	**0.10/0.16**					
Detention Basin	66.9/67.1	**0.24/0.29**					
Manufactured Device	*53.3/31.4*	0.20/0.19	*0.12/0.05*	**0.09/0.30**	0.41/0.41	1.72/1.58	0.25/0.31
Media Filter	**19.0/58.4**	**0.16/0.18**		*0.09/0.03*	*0.55/0.31*	1.16/0.95	
Porous Pavement	**13.1/96.9**	**0.09/0.18**			**0.23/0.53**	**0.63/2.0**	
Retention Pond	77.6/70.5	**0.14/0.30**				**0.86/1.31**	
Wetland Basin	*43.2/12.2*	0.14/0.12			*0.50/0.15*		*0.13/0.03*

Legend

Bold	indicates CBay median influent concentrations are lower
Italic	indicates CBay median influent concentrations are higher
	indicates no significant difference between medians
	indicates too few studies were available for comparison

Table 11. Median Effluent Concentrations for CBay/Non-CBay Studies.

	TSS	TP	DP	OP	NOx	TKN	NH3
Grass Strip	19.5/19.0	**0.16/0.21**		**0.03/0.08**	**0.19/0.46**	**0.93/1.28**	**0.12/0.28**
Bioretention	*9.4/4.8*	*0.09/0.07*					
Detention Basin	21.8/24.9	**0.17/0.24**					
Manufactured Device	*25.8/16.3*	*0.16/0.12*	*0.13/0.05*	**0.07/0.26**	0.39/0.37	1.46/1.48	0.26/0.25
Media Filter	9.7/8.5	0.11/0.09		*0.06/0.02*	*0.79/0.49*	*0.89/0.53*	
Porous Pavement	**9.0/18.0**	0.09/0.09			**0.50/0.95**	**0.61/0.91**	
Retention Pond	13.0/13.6	**0.08/0.13**				**0.66/1.08**	
Wetland Basin	*15.2/3.4*	*0.09/0.08*			*0.25/0.03*		*0.08/0.03*

Legend

Bold	indicates CBay median effluent concentrations are lower
Italic	indicates CBay median effluent concentrations are higher
	indicates no significant difference between medians
	indicates too few studies were available for comparison

While climate and rainfall characteristic likely play an important role in performance differences between BMPs in CBay and non-CBay, watershed size and imperviousness may also contribute to the observed differences between the two data sets. Table 12 compares average watershed size and average watershed imperviousness of CBay and Non-CBay studies. The Non-CBay studies tend to have much larger watersheds for composite BMPs (treatment trains), manufactured devices, media filters, retention ponds, and wetland basins, whereas the CBay studies tend to have larger watersheds for bioretention, grass strips, and detention basins. Comparing imperviousness, the Non-CBay studies have markedly higher average percent imperviousness for bioretention, grass strips, composite BMPs, and green roofs. (Ideally, directly connected impervious area would be used to refine this comparison, but this metric is often not provided with BMP study submittals.) These differences in drainage areas and development characteristics would likely have some influence on the performance of BMPs. These differences may also be reflective of differences in sizing criteria and rainfall characteristics between the Chesapeake Bay region and other areas of the country.

Table 12. Watershed Comparison for CBay/Non-CBay Studies.

	Avg. Watershed Size (ha)		Avg. % Imperviousness	
Category	Non-CBay	CBAY	Non-CBay	CBAY
Grass Strip	0.28	0.49	98	53
Bioretention	0.16	0.43	100	77
Detention Basin	12.9	43.9	47	31
Manufactured Device	3.37	0.59	87	96
Media Filter	57.1	2.24	84	100
Porous Pavement	0.10	0.21	86	1*
Retention Pond	632. 8	59.3	47	48
Wetland Basin	98.8	19.6	56	49

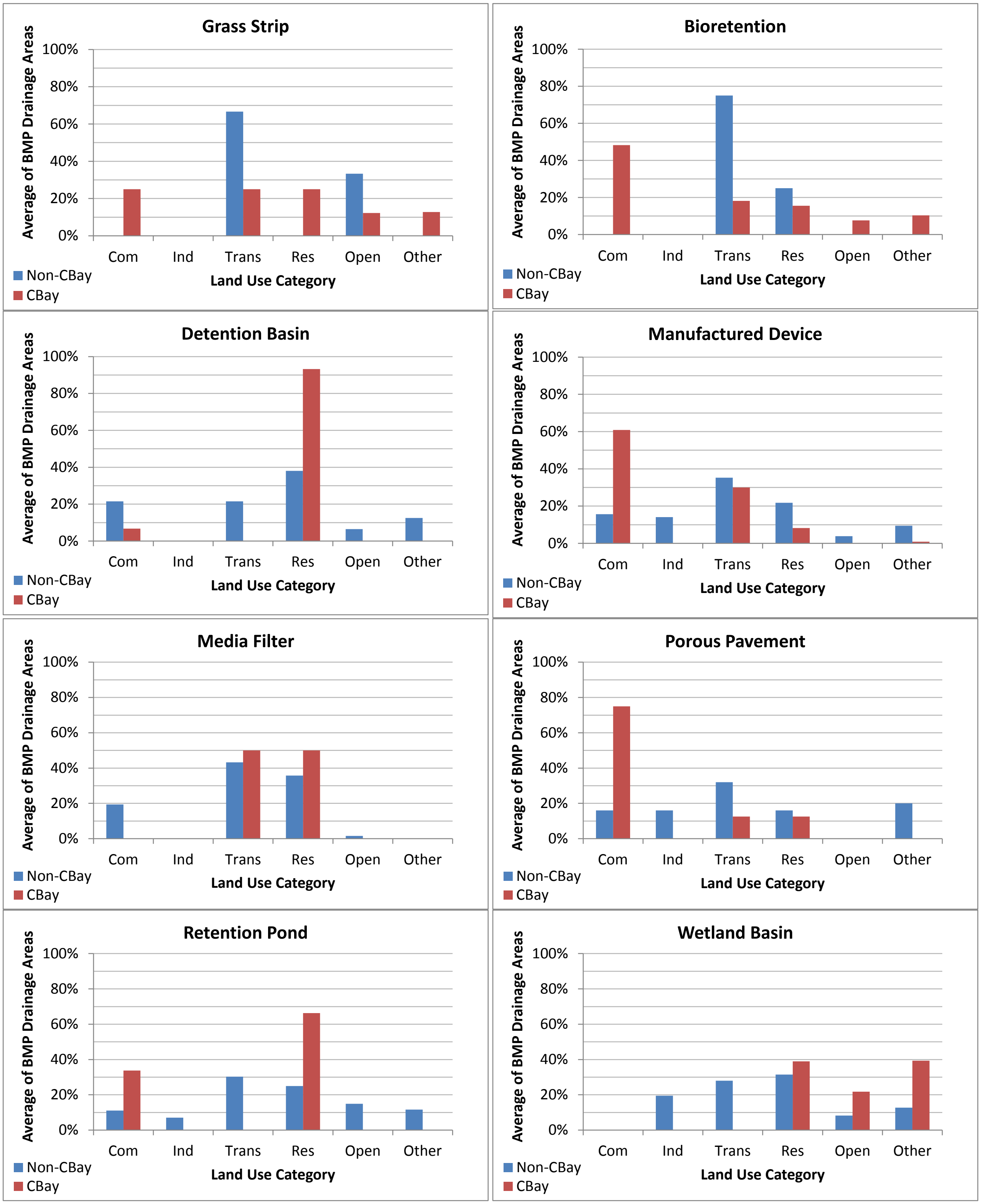
* Data providers vary significantly in how they characterize the imperviousness of porous pavement.

Another potential cause of differences in performance of CBay and Non-CBay studies is the land use characteristics of the BMP watersheds. Figure 14 summarizes the average land use distribution by BMP type for CBay and Non-CBay studies. In the BMPDB, there are several land use categories that researchers can provide to describe the make-up of their BMP watersheds. These have been combined to provide consolidated groups of land uses as follows.

- Ind: Heavy Industrial, Light Industrial
- Trans: Automotive Services, Park & Ride, Roads/Highways, Trans, Maintenance Station, Parking Lots
- Com: Office Commercial, Restaurants, Retail
- Res: High Density Residential, Multi-Family Residential, Medium Density Residential, Low Density Residential
- Open: Open Space, Open Space (Manicured), Rangeland, Forest
- Other: Other, Unknown

As indicated in Figure 14, grass strips and bioretention are dominated by transportation land uses for the Non-CBay studies. In the CBay studies, the grass strip drainage areas are more uniformly distributed across commercial, transportation, and residential land uses. Bioretention drainage areas are dominated by commercial for the CBay studies. These differences in dominant land use may influence the partitioning and speciation of pollutants, and in turn, have an effect on BMP performance. For other BMP categories, the land use distributions are generally similar for CBay and Non-CBay studies. As indicated in all of the figures, there are no CBay BMP studies containing industrial land uses in their tributary watersheds.

Figure 14. Average Land Use Distributions by BMP Type.



3.2 Comparison to Other Data and Studies

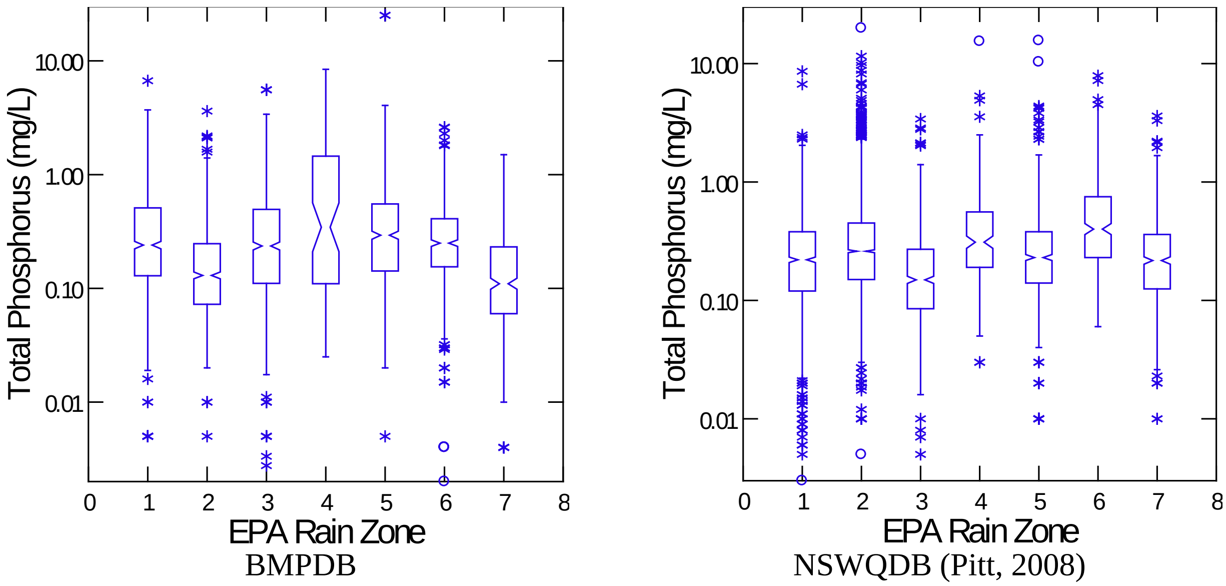
This section evaluates how the data contained in the BMPDB may differ from other data sets and published studies relevant to the Chesapeake Bay.

3.2.1 Comparison to National Stormwater Quality Database (NSQDB)

As discussed above, land use characteristics may have a significant effect on influent concentrations and pollutant characteristics. The National Stormwater Quality Database (NSQDB) (Pitt, 2008) includes stormwater runoff data for sites located throughout the country. These data have been classified according to various factors including dominant land uses in tributary watersheds and EPA rainfall zone. These data can be used to assess the representativeness of the influent concentrations for the CBay BMP studies contained in the BMPDB.

As an example, Figure 15 compares the median total phosphorus (TP) influent concentrations for all BMPs in the BMPDB to the NSWQDBv3 (Pitt, 2008) by EPA rain zone. (Note that the BMPDB does not contain any studies in Zones 8 or 9, so these are not shown in either figure; also Rain Zone 4 in the BMPDB is relatively small and limited to the Harris County, TX geographic area.) As indicated by the plots, there is no clear trend by rain zone except that both data sets have the lowest median TP concentrations in Zone 7 (Pacific Northwest) and the interquartile ranges overlap for all zones. There are similarities between the median TP concentrations for both data sets for Zones 1, 4, and 5. However, the BMPDB has lower TP concentrations in Zones 2, 6, and 7 and the NSWQD has lower TP concentrations in Zone 3. Additional national scale comparisons by rain zone could be done for other constituents, but since the focus here is on Chesapeake Bay, only the NSWQDB data from Zone 2 is considered further below.

Figure 15. TP Influent Concentrations by Rain Zone in BMPDB Compared to NSWQDB.



	Rain Zone						
	1	2	3	4	5	6	7
N	809	776	870	68	686	523	363
25th	0.128	0.072	0.111	0.110	0.142	0.153	0.060
50th	0.240	0.130	0.236	0.345	0.293	0.250	0.110
75th	0.510	0.247	0.495	1.455	0.552	0.410	0.233

	Rain Zone						
	1	2	3	4	5	6	7
N	1165	3476	676	204	732	299	536
25th	0.120	0.150	0.085	0.190	0.140	0.230	0.125
50th	0.220	0.260	0.149	0.310	0.230	0.400	0.217
75th	0.380	0.450	0.270	0.558	0.385	0.750	0.360

Table 13 summarizes the median land use concentrations from the NSQDB for sites in EPA Rain Zone 2 and with dominant land use only (data from sites identified as having mixed land uses were not included). Table 14 compares the ranges of influent medians for the CBay studies (summarized above in Table 10) with the ranges of medians for urban lands (industrial, freeway, residential, commercial, and institutional) for the NSQDB for sites contained within EPA Rain Zone 2. As shown in bold font in the table, the median ranges overlap for TSS, TP, DP, and TKN, but for the other constituents (OP, NOx, and NH3), the BMPDB influent median concentrations are lower. These differences could be related to sampling methods and locations, which may affect the dissolved/particulate fractionation of stormwater pollutants. Many of the data points in the NSQDB are from grab samples collected at storm drain outfalls whereas the BMPDB contains mostly event mean concentrations (EMCs) collected using automated sampling equipment. Further data exploration would be needed to determine the source of the differences.

Table 13. EPA Rain Zone 2 Land Use Medians from the NSQDBv3 (Pitt et al., 2008).

	TSS	TP	DP	OP	NOx	TKN	NH3
Industrial	48.5	0.22	0.10	n/a	0.62	1.15	0.35
Freeway	36.3	0.40	0.10	n/a	1.39	1.95	0.85
Residential	43.0	0.28	0.16	0.13	0.60	1.37	0.30
Commercial	42.0	0.22	0.11	n/a	0.68	1.40	0.50
Institutional	64.3	0.19	0.13	n/a	0.56	1.35	0.31
Open Space	22.0	0.18	0.06	n/a	1.27	0.60	0.25

Table 14. Comparison of Ranges of Medians for BMPDB and NSQDB.

	TSS	TP	DP	OP	NOx	TKN	NH3
BMPDB Influent (CBay)	**13-78**	**0.09-0.24**	**0.12**	0.02-0.09	0.23-0.55	**0.63-1.72**	0.13-0.25
NSQDB Urban Land Uses (EPA Zone 2)	**36-64**	**0.19-0.40**	**0.10-0.16**	0.13*	0.56-1.39	**1.15-1.95**	0.30-0.85

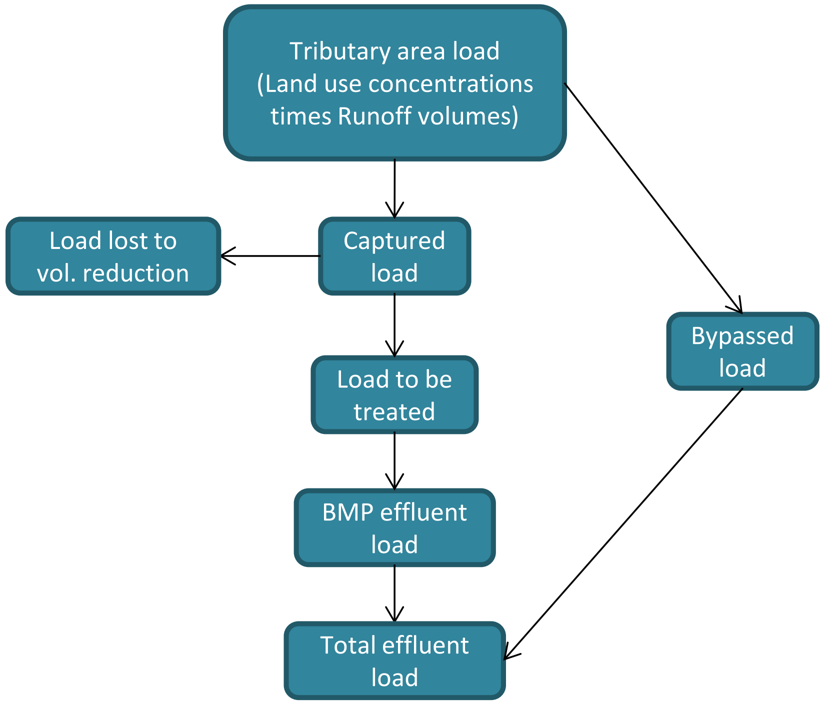
Bolded values indicate the ranges of medians overlap.
*OP data are only available for residential land use, so no range of medians is provided.

3.2.2 Comparison to Chesapeake Bay-Specific Research

The BMP category-level analysis results were also compared to results from other BMP and water quality research for the Chesapeake Bay region contained in the literature. Schueler (2011) summarizes estimated percent mass load reductions for various BMPs that are approved by the Chesapeake Bay Program for use by communities developing TMDL implementation plans. Statistical summaries of the BMPDB focus on achievable effluent concentrations rather than percent load reductions, making performance comparisons between the two information sources less straightforward. As recognized by Schueler (2011), the use of percent removal for summarizing and estimating BMP performance has a number of significant limitations that should be carefully considered (U.S. EPA, 2009; Jones et al., 2008).

Given that percent load reductions are the metric of BMP performance used in the Chesapeake Bay TMDL, percent load reductions have been computed for purposes of this technical summary based on estimates of tributary area loads and BMP effluent loads to calculate the total effluent load as shown in Figure 16. This load accounting procedure incorporates the influence of watershed loading (function of land use and runoff coefficient), volumetric capture efficiency of stormwater BMPs (typically designed for 80-90% capture unless in retrofit situations), volume reductions (BMP, climate, & soil dependent), and median effluent quality as observed from the BMPDB when estimating the total expected load reduction provided by a BMP. The procedure does not rely on percent concentration or load reductions by BMP type, but instead reports the computed load reductions as a percentage of the estimated watershed load.

Figure 16. Load Accounting Procedure for Determining Total Effluent Loads.



The tributary area load can be estimated using various watershed models or, for broad, planning-level comparisons, the Simple Method as summarized in Schueler (1987) can be used. In the Simple Method, the load is computed as the sum product of the mean annual runoff volume times the median concentration for each land use in the watershed. Annual runoff volumes for each land use are computed from the runoff coefficient, area, and average annual rainfall volume.

Only a fraction of this tributary load is typically treated, so the total effluent load is the sum of the bypassed load (10-20% of the tributary load for new and re-development BMPs; less for retrofits in constrained situations) and the BMP effluent load.

Assuming the bypass (or overflow) volume does not get any treatment, the bypass load can be simply estimated as:

$$Bypass\ load = (Tributary\ area\ load) \times (1 - \%Cap)$$

where $\%\ Cap$ is the percent of average annual runoff flow "captured" (i.e. treated or otherwise managed-infiltrated or evapotranspired) by the BMP.

The BMP effluent load can be estimated simply as the effluent volume times the median BMP effluent concentration from the BMPDB:

$$BMP\ effluent\ load = (BMP\ effluent\ volume) \times (BMP\ effluent\ conc.)$$

The effluent volume depends on the annual runoff volume captured by the BMP and the portion of this volume that is reduced in the BMP:

$$BMP\ effluent\ volume = (ROV)(\%\ Cap)(1 - \%VR)$$

where ROV is the annual runoff volume and $\%VR$ is the percent of the captured volume that is lost due to infiltration or evapotranspiration in the BMP.

Volume reduction estimates should ideally be based on water balance accounting methods that consider the BMP footprint, underlying soil type, and local climate conditions, so results using this simplified method should only be used in planning-level analyses and be supported with appropriate caveats in this regard.

Using the above method, total load reduction can be computed by the formula:

$$\%\ Load\ Reduction = \left(1 - \frac{BMP\ effluent\ load + Bypass\ load}{Tributary\ area\ load}\right) \times 100\%$$

In previously completed analyses of the BMPDB (Geosyntec and WWE 2011), average percent volume reductions have been computed by BMP type for studies in the BMPDB that were deemed appropriate for such analysis). These values (Table 15) agree well with the percent annual runoff reductions summarized in Schueler (2011), which were 50% for swales and 60% for bioretention. The volume reductions presented by Schueler did not include detention basins.

Table 15. Summary of Percent Volume Reduction by BMP Type.

BMP Category	# of Studies	25th Percentile	Median	75th Percentile	Average
Biofilter – Grass Strips	16	18%	34%	54%	38%
Biofilter – Grass Swales	13	35%	42%	65%	48%
Bioretention (with underdrains)	7	45%	57%	74%	61%
Detention Basins –Surface, Grass Lined	11	26%	33%	43%	33%

Source: Geosyntec Consultants and Wright Water Engineers (2011). Note: this analysis is currently being updated and is expected to be available in June 2012.

The median effluent concentrations summarized in Section 2 of this summary represent the expected effluent quality observed for various BMP categories, recognizing that half the results will be higher and half will be lower. Additionally, there is typically a lower concentration limit or “irreducible concentration” that BMPs are capable of treating (Schueler, 2000 and 2011). BMPDB effluent medians suggest that some BMPs may be capable of achieving lower minimum effluent concentrations than have been assumed in earlier analysis and it may be worth re-evaluating some more recent BMP performance data for purposes of modeling assumptions. Note that “irreducible” concentrations could become lower over time as BMP designs improve based on such factors as media composition for filters, geometry and configuration of ponds, outlet structure designs, and smart controllers, etc.

Although easy to apply, the percent load removal approach is not recommended for computing potential load reductions for reasons other than conceptual-level planning because it does not account for the complex interplay among runoff volume, runoff quality, percent capture, volume reduction, and achievable effluent concentrations. Tributary areas with different runoff volume and concentration characteristics will have a direct impact on the load reductions achieved by a BMP.

To illustrate these principles, consider three different tributary areas each with homogenous land uses: residential, freeway, and commercial. Each tributary area is assumed to have the runoff coefficients and land use concentrations (NSWQv3, Zone 2 from Table 13) shown in Table 16. For each tributary area, the BMPs shown in Table 17 are evaluated using the procedure outlined in Figure 15.

Table 16. Tributary Land Use Assumptions.

		Median Land Use Concentrations (NSWQv3, Zone 2)					
	Runoff Coeff.	TSS	TP	DP	NOx	TKN	NH3
Residential	0.60	43.0	0.28	0.16	0.60	1.37	0.30
Freeway	0.95	36.3	0.40	0.10	1.39	1.95	0.85
Commercial	0.80	42.0	0.22	0.11	0.68	1.40	0.50

Table 17. BMP Assumptions Used in Load Reduction Calculations.

			BMP Median Effluent Concentrations (mg/L)					
BMP Type	**Capture efficiency**	**% Volume Reduction**	TSS	TP	DP	NOx	TKN	NH3
Grass Strip	85%	34%	19.54	0.16	0.03	0.19	0.93	0.12
Bioretention	85%	57%	9.44	0.09	0.04	0.23	0.6	0.07
Detention Basin	85%	33%	21.82	0.17	NA	NA	NA	NA
Media Filter	85%	0%	9.66	0.11	0.06	0.79	0.89	NA
Porous Pavement	85%	60%	8.97	0.09	0.04	0.5	0.61	NA
Retention Pond	85%	0%	13.03	0.08	NA	NA	0.66	NA
Wetland Basin	85%	0%	15.21	0.09	0.04	0.25	NA	0.08

NA – not available

Table 18 summarizes the load reduction estimates using the load accounting procedure described above. As shown in the table, there can be differences in estimated load reductions for each BMP type and constituent depending on the tributary area characteristics. For example, TSS results are relatively similar among the three land uses for each BMP category, whereas differences of 10-20 percent occur for several BMP categories with regard to total phosphorus and NOx.

Table 18. Percent Load Reduction Results Using Load Accounting Procedure.

	% Load Reductions for Residential Tributary Area					
BMP Type	TSS	TP	DP	NOx	TKN	NH3
Grass Strip	60%	53%	74%	67%	47%	63%
Bioretention	77%	73%	76%	71%	69%	76%
Detention Basin	56%	50%	NA	NA	NA	NA
Media Filters	66%	52%	53%	-27%	30%	NA
Porous Pavement	78%	74%	77%	57%	70%	NA
Retention Pond	59%	61%	NA	NA	44%	NA
Wetland Basin	55%	58%	64%	50%	NA	62%
	% Load Reductions for Freeway Tributary Area					
BMP Type	TSS	TP	DP	NOx	TKN	NH3
Grass Strip	55%	63%	68%	77%	58%	77%
Bioretention	75%	77%	70%	79%	74%	82%
Detention Basin	51%	61%	NA	NA	NA	NA
Media Filters	62%	62%	34%	37%	46%	NA
Porous Pavement	77%	77%	71%	73%	74%	NA
Retention Pond	54%	68%	NA	NA	56%	NA
Wetland Basin	49%	66%	51%	70%	NA	77%
	% Load Reductions for Commercial Tributary Area					
BMP Type	TSS	TP	DP	NOx	TKN	NH3
Grass Strip	59%	44%	70%	69%	48%	72%
Bioretention	77%	70%	72%	73%	69%	80%
Detention Basin	55%	41%	NA	NA	NA	NA
Media Filters	65%	43%	39%	-14%	31%	NA
Porous Pavement	78%	71%	73%	60%	70%	NA
Retention Pond	59%	54%	NA	NA	45%	NA
Wetland Basin	54%	50%	54%	54%	NA	71%

Table 19 compares these BMPDB CBay values (and values obtained using median effluent concentrations for the entire BMPDB) to the load reductions recommended in Schueler (2011) for the Chesapeake Bay program. The BMPDB estimates are expressed as the range of values associated with the three homogenous land use tributary areas analyzed for load reductions presented in Table 18. Assuming that a difference of less than 20% from an outer range value from the BMPDB and Schueler's values indicates agreement, the values shaded green are in general agreement whereas the values shaded **red bold** are not. For comparison purposes, it was assumed that grass strips perform similarly to bioswales and that TKN behaves similarly to TN for the BMPs without available TN data.

As shown in the table, the Chesapeake Bay Program load reduction values presented in Schueler (2011) are comparable for a number of BMP category-constituent combinations. For example, bioretention and wetland basin load reductions are in general agreement for all constituents. Schueler's removal estimates are higher for grass strips with TSS. Conversely, poorer load reduction performance is assumed in Schueler (2011) for detention basin/TP, porous pavement/TP, porous pavement/TKN, and retention pond/TKN combinations. These results suggest that the BMP Database may be helpful in refining estimates of BMP performance for Chesapeake Bay. Additionally, although this comparison is based on a hypothetical example, it also indicates that load reductions may vary substantially for different tributary watershed characteristics. Note that there are significant discrepancies in effluent concentrations between the full BMPDB and CBay only studies for detention basins/TP and retention pond/TKN, which affect the load reduction estimates for these BMP/constituent combinations. Additional research and data (particularly for retention ponds in CBay) are needed to fully evaluate the potential causes for these differences in performance estimates.

Table 19. Comparison of Percent Load Reduction Estimates Derived from BMP Database to Chesapeake Bay Program Values in Schueler (2011).

		% Load Reductions					
BMP Type	Source	TSS	TP	DP	NOx	TKN	NH3
Grass Strip	BMPDB Full DB	**55 to 60%**	39 to 60%	51 to 64%	60 to 74%	47 to 58%	63 to 77%
	BMPDB CBay	**55 to 60%**	44 to 63%	68 to 74%	67 to 77%	40 to 54%	53 to 74%
	Schueler	80%	75%			70%	
Bioretention	BMPDB Full DB	77 to 78%	70 to 77%	70 to 76%	72 to 79%	69 to 74%	76 to 82%
	BMPDB CBay	75 to 77%	70 to 77%	70 to 76%	71 to 79%	69 to 74%	76 to 82%
	Schueler	55 - 80%	45 - 75%			25 - 70%	
Detention Basin	BMPDB Full DB	47 to 53%	28 to 54%	17 to 42%	51 to 70%	NA	NA
	BMPDB CBay	51 to 56%	**41 to 61%**	NA	NA	18 to 38%	66 to 78%
	Schueler	60%	20%			20%	
Media Filters	BMPDB Full DB	65 to 68%	50 to 66%	51 to 64%	13 to 54%	30 to 46%	NA
	BMPDB CBay	62 to 66%	43 to 62%	34 to 53%	-27 to 37%	50 to 60%	62 to 77%
	Schueler	80%	60%			40%	
Porous Pavement	BMPDB Full DB	73 to 75%	**71 to 77%**	68 to 74%	45 to 68%	**70 to 74%**	NA
	BMPDB CBay	77 to 78%	**71 to 77%**	71 to 77%	57 to 73%	**65 to 71%**	NA
	Schueler	55 - 70%	20 - 50%			10 - 45%	
Retention Pond	BMPDB Full DB	53 to 58%	35 to 57%	43 to 58%	60 to 74%	**44 to 56%**	NA
	BMPDB CBay	54 to 59%	54 to 68%	NA	NA	20 to 39%	57 to 75%
	Schueler	60%	45%			20%	
Wetland Basin	BMPDB Full DB	64 to 67%	54 to 68%	60 to 69%	74 to 80%	NA	62 to 77%
	BMPDB CBay	49 to 55%	50 to 66%	51 to 64%	50 to 70%	22 to 41%	71 to 80%
	Schueler	60%	45%			20%	

Notes:
1) A range is presented on Schueler's bioretention and porous pavement BMPs to account for the range of performance for these BMPs assuming underdrains and depending on underlying soil types.
2) Computed values are expressed as a range of pollutant load reduction results for different land uses tributary areas presented in Table 18.
3) NA = Not available
4) Red values indicate a difference of 20% or more between the two information sources.
5) Green values represent general agreement between the two information sources (< 20% discrepancy).

4 CONCLUSIONS AND RECOMMENDATIONS

Key conclusions from the data exploration and analysis effort presented in this technical summary include:

- BMP performance for BMPs in the Chesapeake Bay watershed is generally similar to that observed in other parts of the United States for most BMP types for the constituents evaluated in this technical summary. Where difference exists in median effluent concentrations, the relative performance trends are generally similar (e.g., the best and worst performing BMPs for a particular constituent are typically in agreement).
- Most BMP types can achieve TSS effluent concentrations below 20 mg/L, but filtration based BMPs (bioretention and media filters) are the most effective, with median effluent concentrations around 10 mg/L, followed by BMPs with permanent pools (retention ponds and wetland basins) with median effluent concentrations of about 15 mg/L.
- Media filters, retention ponds and wetland basins tend to achieve the most dramatic decreases in phosphorus concentrations with median effluent TP and DP/OP concentrations of approximately 0.1 mg/L and 0.05 mg/L, respectively.
- Grass strips and bioretention have the potential to increase phosphorus concentrations, particularly when influent concentrations are low. For bioretention, results may also be influenced based on media characteristics.
- Bioretention and retention ponds are the only BMPs with data supporting statistically significant concentration reductions of total nitrogen.
- None of the BMP categories in the BMPDB show consistent concentration reductions for nitrate, but grass strips, bioretention, and wetland basins performance results suggest removal may be occurring for some BMPs.
- BMP Database results suggest that media filters and porous pavement have the potential to increase nitrate concentrations.
- Median influent concentrations are lower for many constituents for the CBay studies relative to other studies in the BMPDB and as compared to median land use concentrations presented in the National Stormwater Quality Database. There are several potential explanations for these differences, but more in depth comparison of the data sets would be needed to determine the source of the differences.
- A number of BMPs have shown demonstrated volume reductions. Therefore, even for some BMPs where effluent concentrations are not significantly reduced (or even increased by a small amount), overall loads can be reduced.
- A simple load reduction accounting procedure using median effluent concentrations and assumptions of percent volume capture and loss by various BMP types was applied to the summarized BMPDB data to facilitate comparisons to Chesapeake Bay load reduction assumptions summarized by Schueler (2011). This accounting procedure incorporates a number of factors that influence BMP performance (e.g., percent of runoff captured and treated, percent of volume reduced, and typical effluent concentrations). Stormwater

practitioners in the Chesapeake Bay who are charged with estimating the load reductions expected from various practices as part of TMDL implementation planning may benefit from explicitly considering how variations in the various components of this procedure (e.g., percent capture, volume reduction, effluent concentration) may help to maximize load reductions in the future.

5 ATTACHMENTS

Attachment 1. Statistical Summary Report for TSS
Attachment 2. Statistical Summary Report for Nutrients

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International Stormwater Best Management Practices (BMP) Database

Attachment 1:

Statistical Summary Report for TSS Chesapeake Bay and Related Areas

Prepared by
Geosyntec Consultants, Inc.
Wright Water Engineers, Inc.

Under Support From
National Fish and Wildlife Foundation
Water Environment Research Foundation

May 2012

Contents

1 Description of Statistics Used in this Report

This report provides a concise statistical summary of BMP performance data contained in the International Stormwater BMP Database. The analysis focuses on the distribution of effluent water quality from individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of data points reported. In other words, the performance analysis presented in this technical summary is “storm-weighted”, as opposed to “BMP weighted”[1].

The statistical summaries have been organized by BMP and then by constituent. For each data set, influent and effluent summary statistics are presented in a table followed by graphical summaries.

1.1 Tabular Summaries

The summary tables include both parametric and non-parametric statistics. Parametric statistics operate under the assumption that data arise from a single statistical distribution that can be described mathematically using coefficients, or parameters, of that distribution. The mean and standard deviation are example parameters of the normal, or Gaussian, distribution. Non-parametric statistics are fundamentally based on the ranks[2] of the data with no need to assume an underlying distribution. Non-parametric statistics do not depend on the magnitude of the data and are therefore resistant to the occurrence of a few extreme values (i.e., high or low values relative to other data points do not significantly alter the statistic)[3].

Table 1.1 summarizes the parametric and non-parametric statistics commonly used to describe data sets. Definitions for each summary statistic included in the tables are provided in Table 1.2.

Table 1.1: Example Common Parametric and Non-Parametric Descriptive Statistics

Statistic Category	**Parametric**	**Non-Parametric**
Measures of Location	Mean	Median
Measures of Spread	Variance, Standard Deviation	Interquartile Range, Median Absolute Deviation
Measures of Skew	Coefficient of Skewness	Quartile Skew Coefficient

1.2 Graphical Summaries

In addition to the summary tables provided for each BMP/constituent combination, influent/effluent box plots and non-exceedance probability plots are provided. Box plots (or box and whisker plots) provide a schematic representation of the central tendency and spread of the influent and effluent data sets. Box plots can also be

[1] There are several viable approaches to evaluating the BMP Database. Two general approaches that have been presented in the past (Geosyntec and WWE 2008) are the “BMP-weighted” and “storm-weighted” approaches. The BMP-weighted approach represents each BMP with one value representing the central tendency of the BMP study, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data set. The storm-weighted approach has been selected for this report.

[2] In this context, ranks refer to the positions of the data after being sorted by magnitude.

[3] Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 pages. http://pubs.usgs.gov/twri/twri4a3/

used to indicate whether the influent median is statistically different than the effluent median. A key for the box plots is provided in Figure 1.1.

Probability plots illustrate the empirical distribution of the data. A comparison of the influent and effluent probability plots indicates whether there may be differences among all percentiles (not just the median) and whether the influent and effluent data sets are similarly distributed. Probability plots also provide a quick method of identifying the probability that an individual sample would be less than or equal to a particular value. For example, the effluent probability plot may be used to identify the probability that a particular water quality threshold would be met (e.g., 40% chance that effluent concentration would be less than or equal to 1 mg/L). It should be noted, however, that there is not a one-to-one correlation between the percentiles in the influent data and the percentiles in the effluent data. For example, the median influent concentration and the median effluent concentrations may not occur in the EMC samples collected during the same storm. Although the influent and effluent concentrations in a probability plot are not paired values, the relative position and slope of the two populations are a good indication of the effectiveness of the BMP. When generating the probability plots, the detection limits were used for non-detect values (i.e., ROS estimates or half the DL were not used). Non-detects are depicted as triangles pointing down for influent data and pointing up for effluent data.

Influent vs. effluent scatterplots depict paired data to provide an indication of how effluent concentrations may be related to the influent concentrations. Data points below the 45 degree line indicate removals whereas data points above the 45 degree line indicate increases. Detection limits are shown for non-detect values. If both the influent and effluent are non-detect, then a diamond symbol is used. If only the effluent is non-detect then a triangle symbol pointing up is used. If only the influent is non-detect, then a triangle symbol pointing down is used.

Table 1.2: Common Parametric and Non-Parametric Descriptive Statistics

Statistic	Definition/Description
Count	Total number of data points analyzed. Most BMP data sets include only event mean concentrations (EMCs). The exception includes BMPs with permanent pools (retention ponds and wetland basins) where grab samples were also included.
Number of Non-detects	The number of censored values that were reported below the analytical detection limits. Laboratory estimated values (i.e., "J" values) were treated as detected values. The plotting position, or regression-on-order statistics (ROS), method described in Helsel and Cohn (1988)[4] was used to estimate censored values using the distribution of uncensored values for each study.
Mean (95% conf. interval)	The mean of the data points and the 95% confidence interval (CI) about the mean. Provides a parametric measure of the central tendency. The confidence interval was computed using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993)[5].
Std. Dev.	The standard deviation of the data points.
Coeff. of Variation	The ratio of the standard deviation to the absolute value of the mean.
Skewness	The coefficient of skewness of the data points.

Continued on next page

Table 1.2 – continued from previous page

Statistic	Definition/Description
Median (95% conf. interval)	The median of the data points and the 95% confidence interval (CI) about the median. The confidence interval was computed using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993)[5].
25th, 75th percentiles	The difference between the 25th and 75th percentiles is the interquartile range, which is a non-parametric measure of the spread of the data.
Number of paired data	The number of storm events where influent and effluent samples were simultaneously collected.
Wilcoxon p-value	The statistical significance value for the signed-rank test, which is based on the alternative hypothesis that the median of the paired influent/effluent differences is not equal to zero. This non-parametric test applies only to paired data sets and is performed on log-transformed data (base 10) to improve the symmetry of the distribution of the differences between the data pairs. A p-value less than 0.05 indicates that the influent and effluent concentrations are statistically significantly different at the 95% confidence level.
Mann-Whitney p-value	The statistical significance value for the rank-sum test, which is based on the alternative hypothesis that the influent and effluent medians differ. This non-parametric test applies to two independent data sets. A p-value less than 0.05 indicates that the influent and effluent median concentrations are statistically significantly different at the 95% confidence level.

[4]Helsel, D.R. and T. A. Cohn (1988). "Estimation of descriptive statistics for multiply censored water quality data", *Wat. Resour. Res.* 24, 1997-2004.

[5]Efron, B. and R. Tibishirani (1993). *An Introduction to the Bootstrap.* Chapman & Hall, New York.

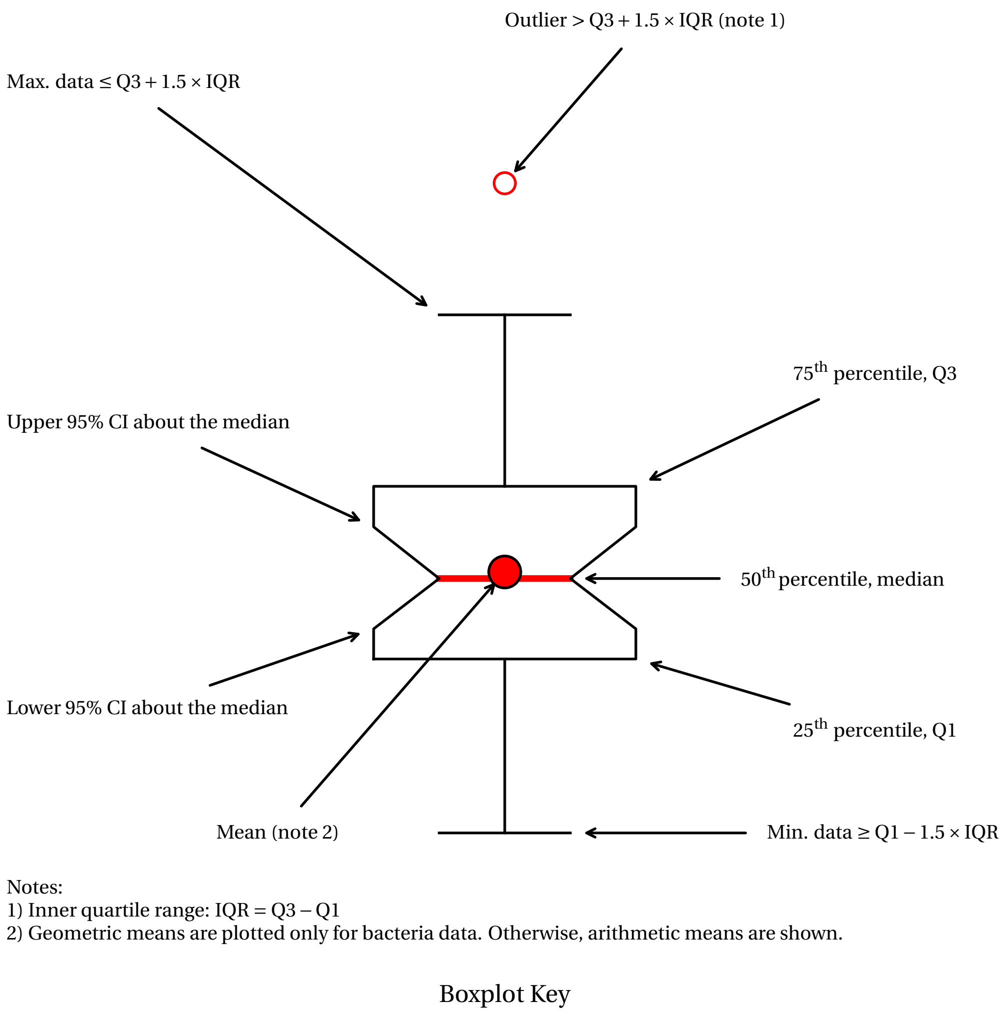


Figure 1.1: Graphical explanation of box and whisker plots

2 Grass Strip

Table 2.1: Summary of Total Suspended Solids at Grass Strip BMPs

Statistic	**Inlet**	**Outlet**
Count	140	123
Number of Non-detects	0	0
Number of Studies	8	8
Min, Max (mg/L)	4.0, 646	1.0, 191
Mean (mg/L) (95% confidence interval)	58.9 (44.4, 75.3)	31.6 (25.1, 38.3)
Standard Deviation (mg/L)	90.4	37.3
Geometric Mean (mg/L) (95% confidence interval)	27.9 (23.0, 34.0)	18.8 (15.8, 22.7)
Geometric Standard Deviation (mg/L)	3.29	2.79
Coefficient of Variation	1.58	1.19
Skewness	4.02	2.59
Median (mg/L) (95% confidence interval)	26.8 (20.6, 35.0)	19.6 (13.0, 24.0)
25^{th}, 75^{th} percentiles (mg/L)	9.0, 63.0	9.0, 36.0
Number of data pairs	122	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.019	

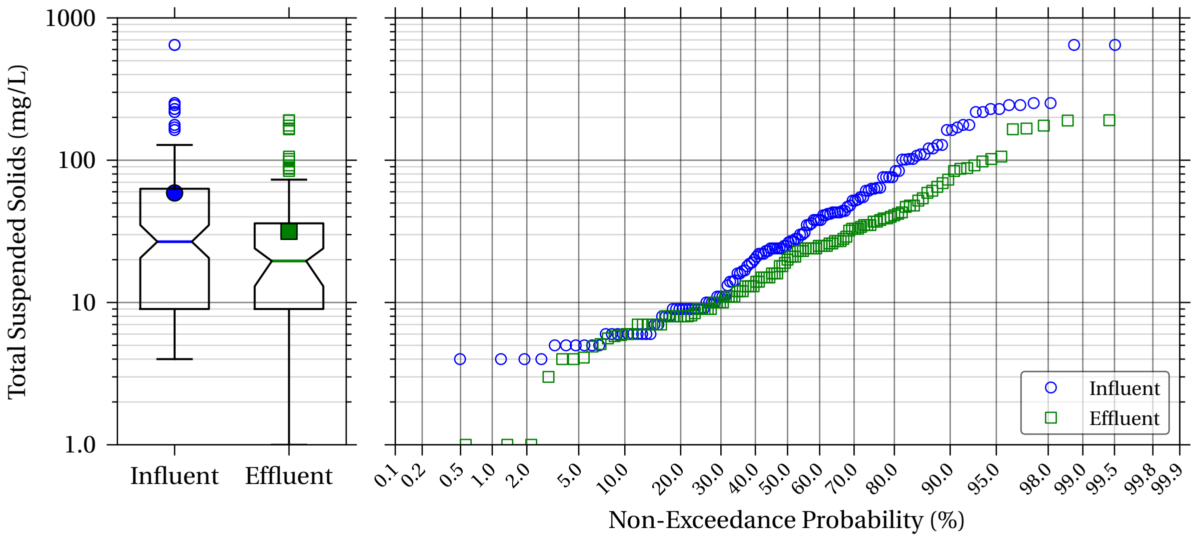


Figure 2.1: Box and Probability Plots of Total Suspended Solids at Grass Strip BMPs

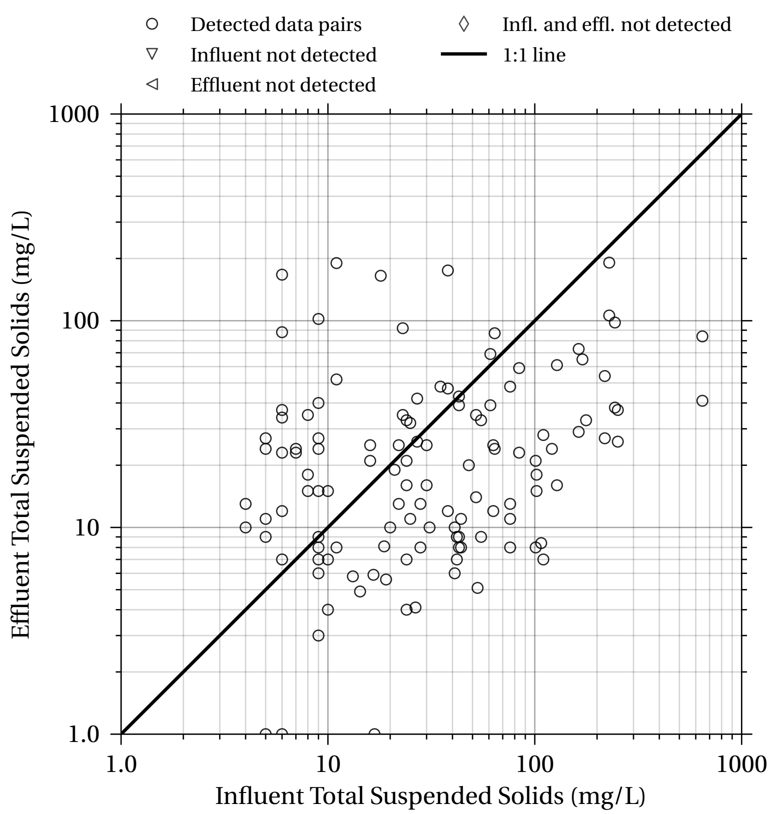


Figure 2.2: Influent vs. Effluent Plots of Total Suspended Solids at Grass Strip BMPs

3 Bioretention

Table 3.1: Summary of Total Suspended Solids at Bioretention BMPs

Statistic	Inlet	Outlet
Count	144	138
Number of Non-detects	0	11
Number of Studies	11	11
Min, Max (mg/L)	2.0, 888	0.501, 235
Mean (mg/L) (95% confidence interval)	68.1 (50.1, 86.7)	19.4 (14.3, 24.8)
Standard Deviation (mg/L)	109	31.2
Geometric Mean (mg/L) (95% confidence interval)	34.3 (28.6, 41.1)	9.39 (7.71, 11.4)
Geometric Standard Deviation (mg/L)	3.02	3.22
Coefficient of Variation	1.64	1.65
Skewness	4.16	3.95
Median (mg/L) (95% confidence interval)	29.5 (23.0, 35.5)	9.44 (7.0, 10.6)
25^{th}, 75^{th} percentiles (mg/L)	16.0, 68.8	5.0, 16.8
Number of data pairs	135	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

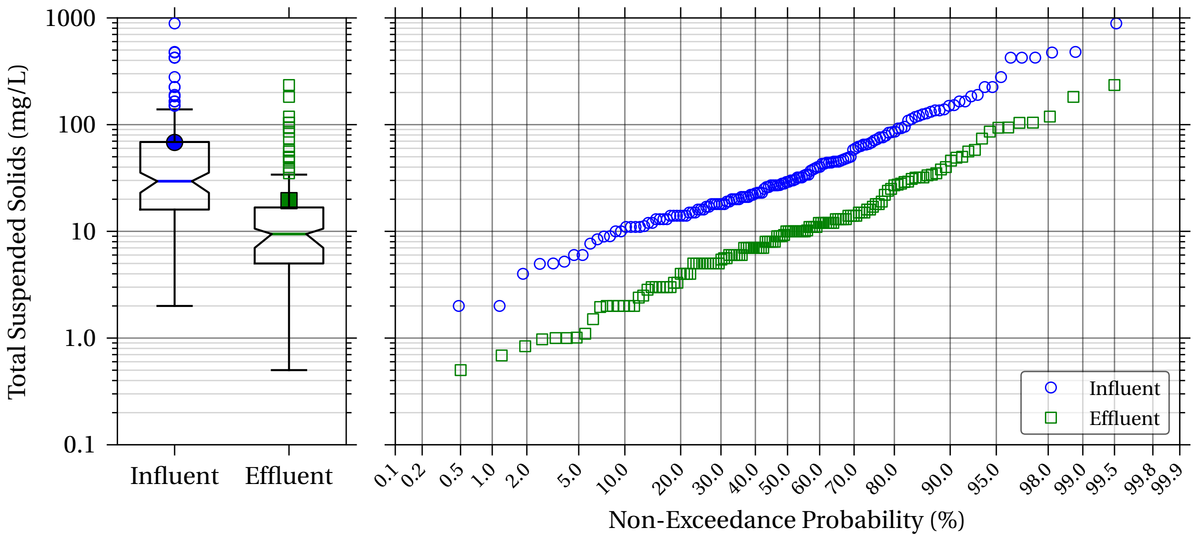


Figure 3.1: Box and Probability Plots of Total Suspended Solids at Bioretention BMPs

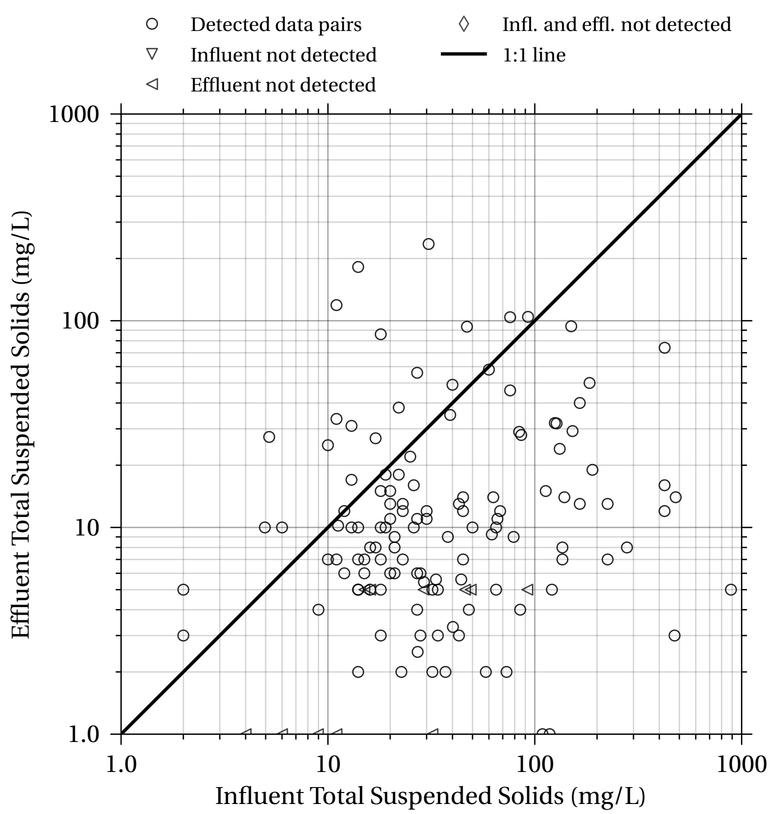


Figure 3.2: Influent vs. Effluent Plots of Total Suspended Solids at Bioretention BMPs

4 Detention Basin

Table 4.1: Summary of Total Suspended Solids at Detention Basin BMPs

Statistic	**Inlet**	**Outlet**
Count	55	79
Number of Non-detects	0	0
Number of Studies	6	7
Min, Max (mg/L)	1.3, 455	1.8, 421
Mean (mg/L) (95% confidence interval)	86.8 (66.7, 108)	42.8 (29.3, 57.9)
Standard Deviation (mg/L)	76.7	64.3
Geometric Mean (mg/L) (95% confidence interval)	54.9 (41.1, 72.7)	21.6 (16.6, 27.7)
Geometric Standard Deviation (mg/L)	3.0	3.12
Coefficient of Variation	0.909	1.56
Skewness	2.08	3.73
Median (mg/L) (95% confidence interval)	66.7 (45.6, 90.2)	21.8 (14.0, 27.0)
25^{th}, 75^{th} percentiles (mg/L)	32.8, 110	10.0, 46.5
Number of data pairs	54	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

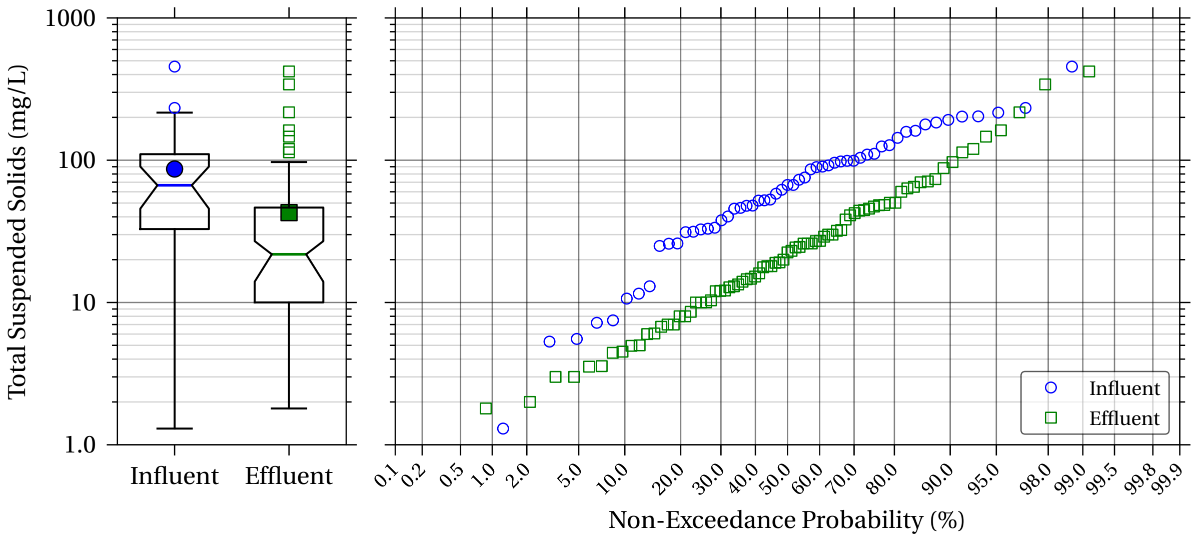


Figure 4.1: Box and Probability Plots of Total Suspended Solids at Detention Basin BMPs

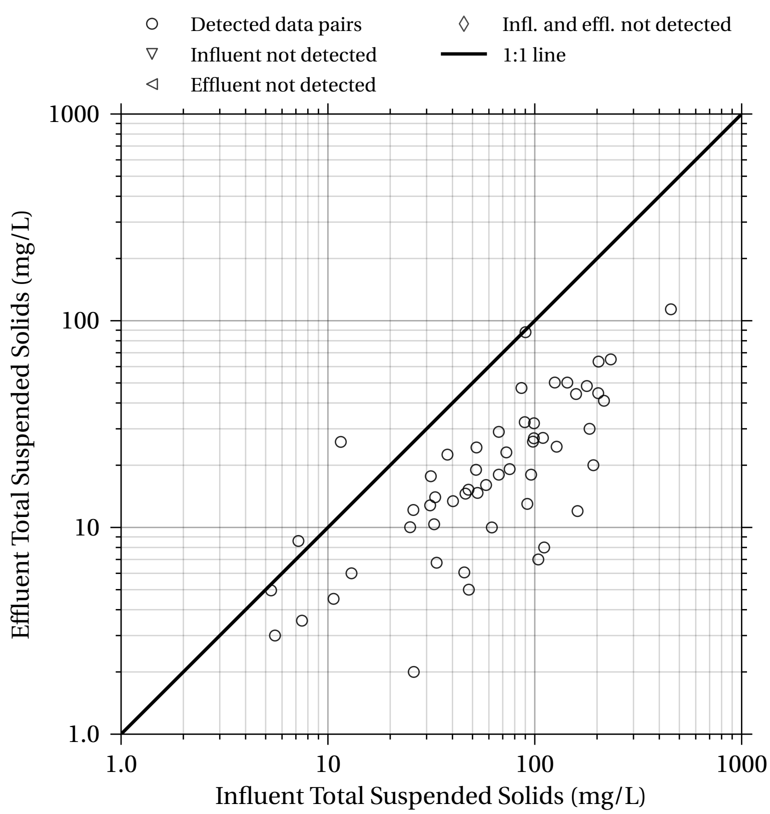


Figure 4.2: Influent vs. Effluent Plots of Total Suspended Solids at Detention Basin BMPs

5 Manufactured Device

Table 5.1: Summary of Total Suspended Solids at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	147	146
Number of Non-detects	0	0
Number of Studies	14	14
Min, Max (mg/L)	3.0, 6900	2.3, 980
Mean (mg/L) (95% confidence interval)	216 (122, 320)	68.9 (46.7, 93.0)
Standard Deviation (mg/L)	599	141
Geometric Mean (mg/L) (95% confidence interval)	64.5 (52.0, 80.6)	27.2 (22.2, 33.4)
Geometric Standard Deviation (mg/L)	3.81	3.48
Coefficient of Variation	3.0	2.09
Skewness	7.98	4.17
Median (mg/L) (95% confidence interval)	53.3 (37.0, 64.0)	25.8 (20.5, 32.0)
25^{th}, 75^{th} percentiles (mg/L)	27.5, 128	11.4, 47.8
Number of data pairs	146	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

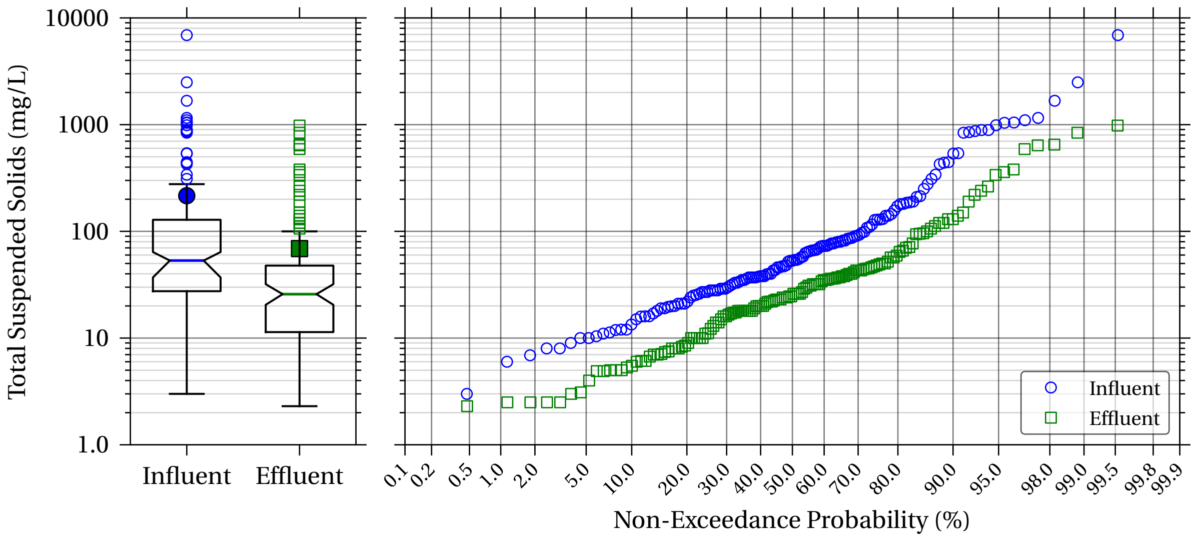


Figure 5.1: Box and Probability Plots of Total Suspended Solids at Manufactured Device BMPs

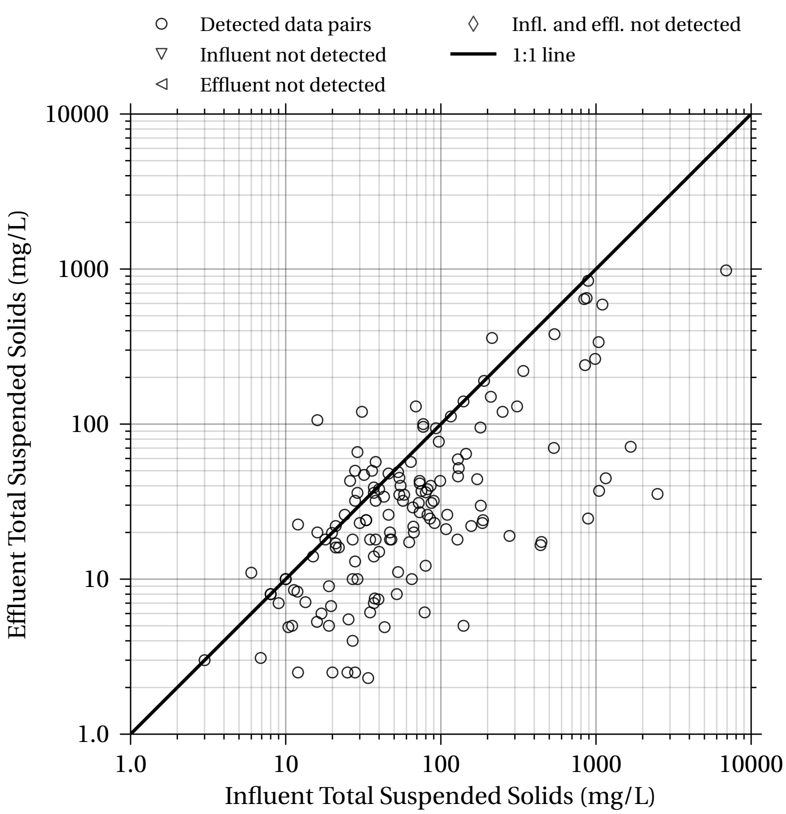


Figure 5.2: Influent vs. Effluent Plots of Total Suspended Solids at Manufactured Device BMPs

6 Media Filter

Table 6.1: Summary of Total Suspended Solids at Media Filter BMPs

Statistic	**Inlet**	**Outlet**
Count	57	62
Number of Non-detects	1	4
Number of Studies	4	5
Min, Max (mg/L)	0.953, 230	0.995, 211
Mean (mg/L) (95% confidence interval)	41.1 (28.3, 54.4)	15.7 (10.1, 22.6)
Standard Deviation (mg/L)	51.0	24.7
Geometric Mean (mg/L) (95% confidence interval)	20.2 (14.6, 27.7)	9.2 (7.26, 11.6)
Geometric Standard Deviation (mg/L)	3.34	2.62
Coefficient of Variation	1.27	1.75
Skewness	1.88	5.92
Median (mg/L) (95% confidence interval)	18.9 (11.0, 31.0)	9.66 (6.0, 11.0)
25^{th}, 75^{th} percentiles (mg/L)	8.0, 45.0	5.0, 17.5
Number of data pairs	56	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

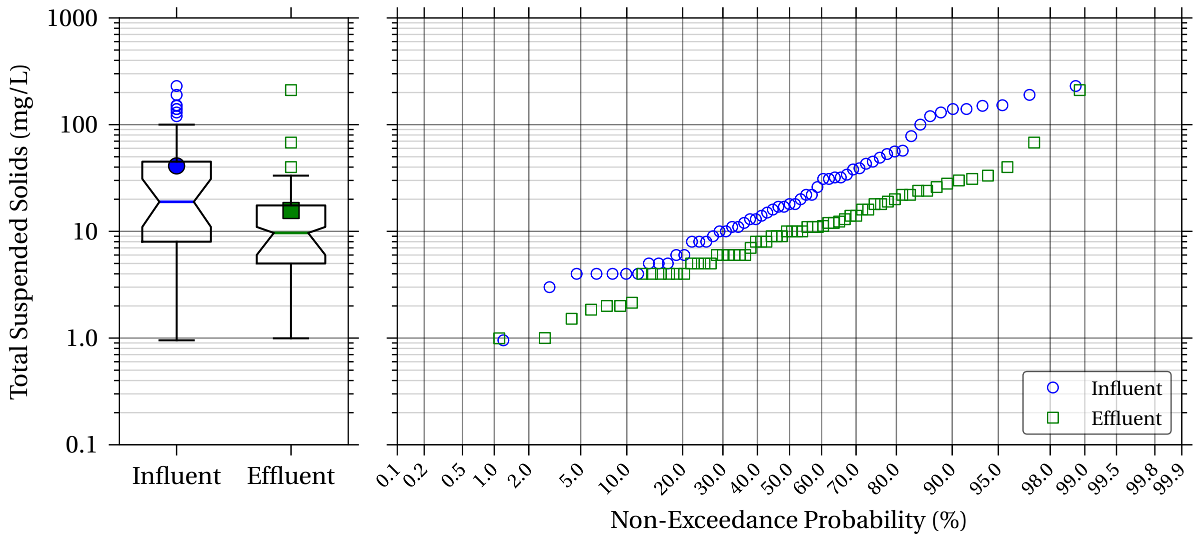


Figure 6.1: Box and Probability Plots of Total Suspended Solids at Media Filter BMPs

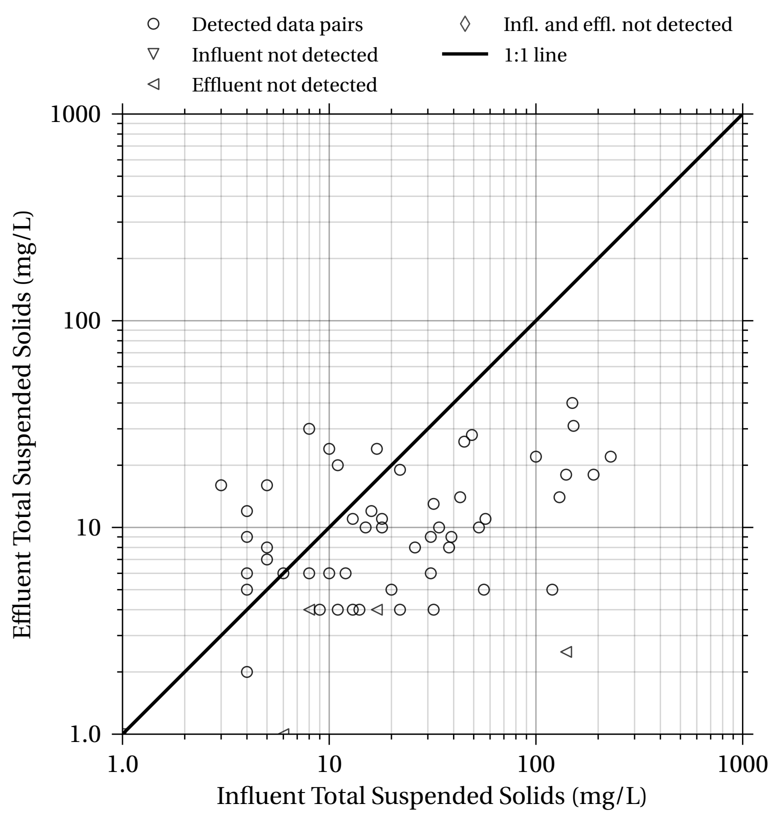


Figure 6.2: Influent vs. Effluent Plots of Total Suspended Solids at Media Filter BMPs

7 Porous Pavement

Table 7.1: Summary of Total Suspended Solids at Porous Pavement BMPs

Statistic	**Inlet**	**Outlet**
Count	49	147
Number of Non-detects	0	1
Number of Studies	5	10
Min, Max (mg/L)	3.0, 236	0.5, 178
Mean (mg/L) (95% confidence interval)	21.2 (12.2, 31.8)	14.8 (11.9, 17.9)
Standard Deviation (mg/L)	34.0	18.4
Geometric Mean (mg/L) (95% confidence interval)	11.5 (8.77, 15.3)	10.0 (8.76, 11.4)
Geometric Standard Deviation (mg/L)	2.62	2.26
Coefficient of Variation	1.75	1.29
Skewness	4.46	5.11
Median (mg/L) (95% confidence interval)	13.1 (5.0, 17.7)	8.97 (7.0, 9.0)
25^{th}, 75^{th} percentiles (mg/L)	5.0, 21.0	6.0, 15.0
Number of data pairs	47	
Wilcoxon p-value	0.059	
Mann-Whitney p-value	0.406	

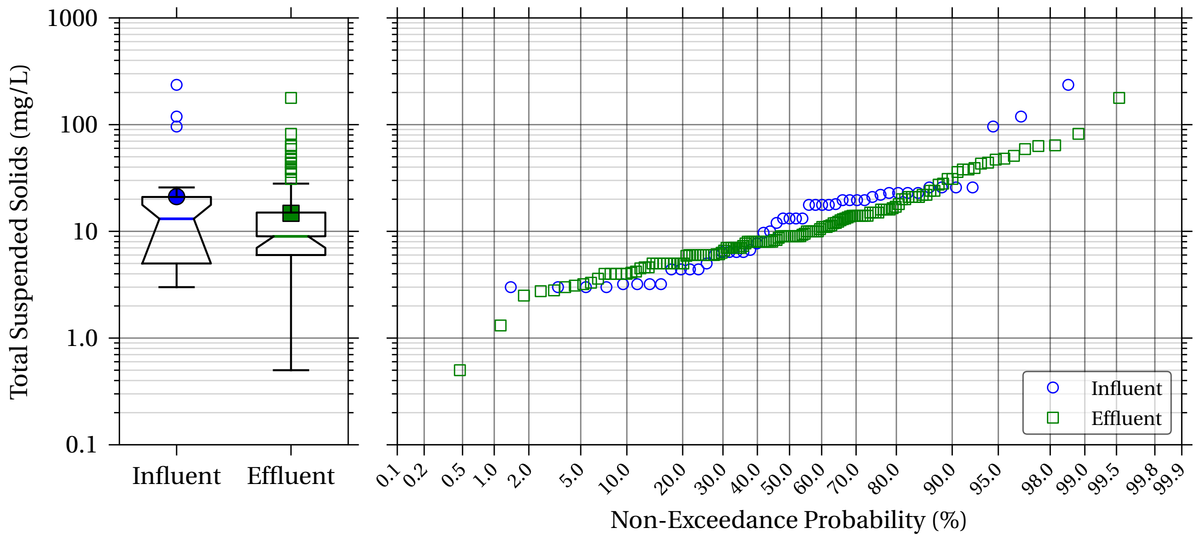


Figure 7.1: Box and Probability Plots of Total Suspended Solids at Porous Pavement BMPs

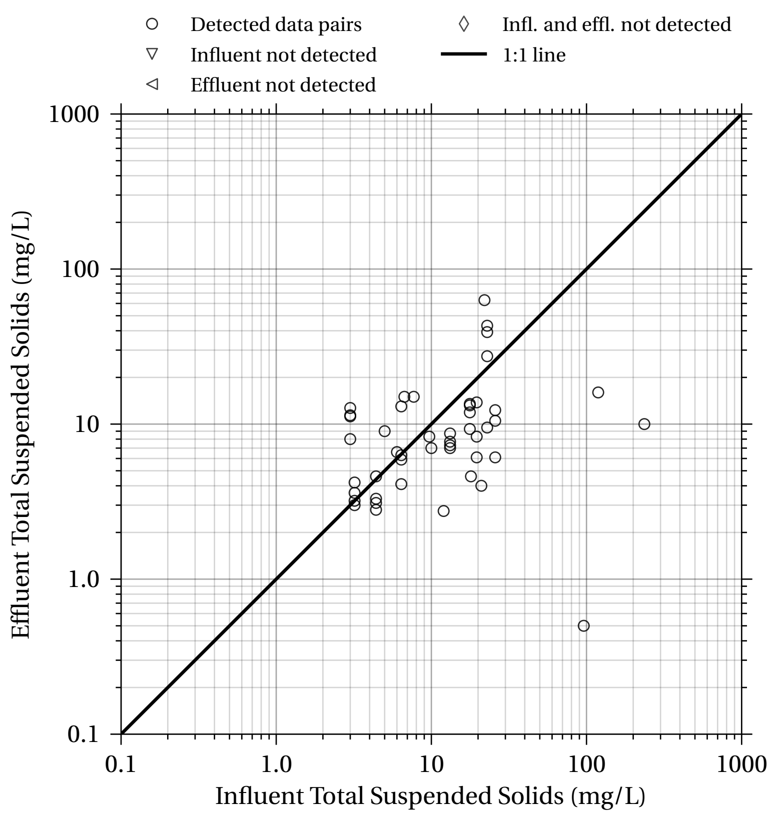


Figure 7.2: Influent vs. Effluent Plots of Total Suspended Solids at Porous Pavement BMPs

8 Retention Pond

Table 8.1: Summary of Total Suspended Solids at Retention Pond BMPs

Statistic	Inlet	Outlet
Count	24	34
Number of Non-detects	0	3
Number of Studies	4	4
Min, Max (mg/L)	13.0, 341	2.0, 112
Mean (mg/L) (95% confidence interval)	83.0 (60.5, 109)	22.6 (14.4, 31.1)
Standard Deviation (mg/L)	57.8	24.5
Geometric Mean (mg/L) (95% confidence interval)	66.3 (49.9, 87.3)	13.5 (9.59, 18.9)
Geometric Standard Deviation (mg/L)	1.96	2.71
Coefficient of Variation	0.754	1.12
Skewness	2.76	1.98
Median (mg/L) (95% confidence interval)	77.8 (51.0, 95.0)	13.0 (6.0, 15.5)
25^{th}, 75^{th} percentiles (mg/L)	51.0, 96.5	6.0, 31.0
Number of data pairs	23	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

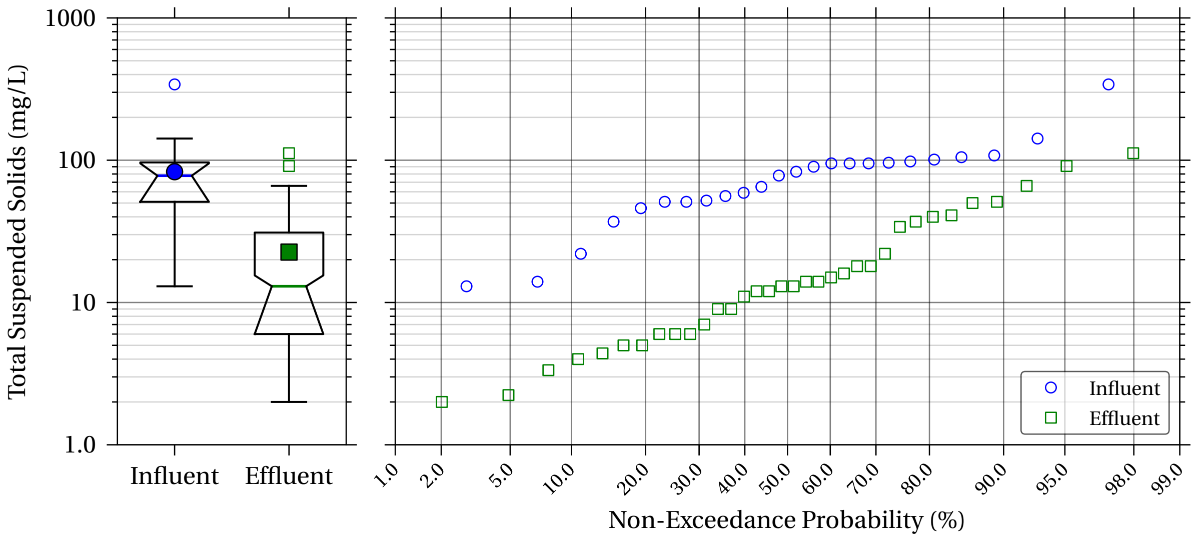


Figure 8.1: Box and Probability Plots of Total Suspended Solids at Retention Pond BMPs

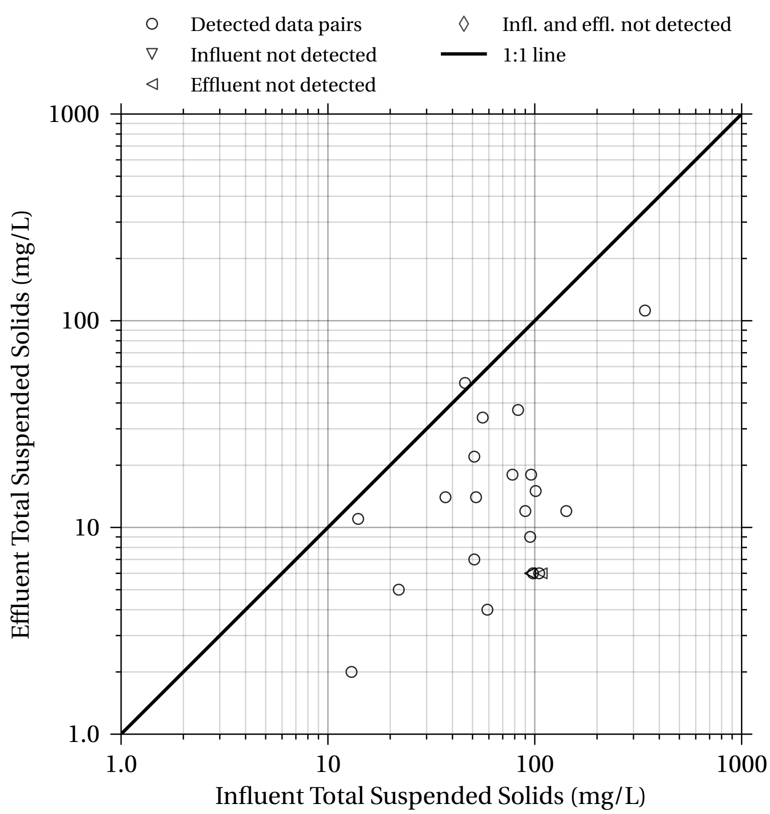


Figure 8.2: Influent vs. Effluent Plots of Total Suspended Solids at Retention Pond BMPs

9 Wetland Basin

Table 9.1: Summary of Total Suspended Solids at Wetland Basin BMPs

Statistic	Inlet	Outlet
Count	132	132
Number of Non-detects	1	0
Number of Studies	7	7
Min, Max (mg/L)	0.742, 1260	0.42, 731
Mean (mg/L) (95% confidence interval)	75.3 (57.0, 96.7)	35.1 (23.4, 48.7)
Standard Deviation (mg/L)	112	72.3
Geometric Mean (mg/L) (95% confidence interval)	42.7 (35.2, 51.3)	16.5 (13.5, 20.0)
Geometric Standard Deviation (mg/L)	2.99	3.12
Coefficient of Variation	1.61	2.19
Skewness	7.19	6.54
Median (mg/L) (95% confidence interval)	43.3 (31.5, 52.9)	15.2 (12.0, 17.3)
25^{th}, 75^{th} percentiles (mg/L)	21.4, 91.8	8.46, 33.3
Number of data pairs	105	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

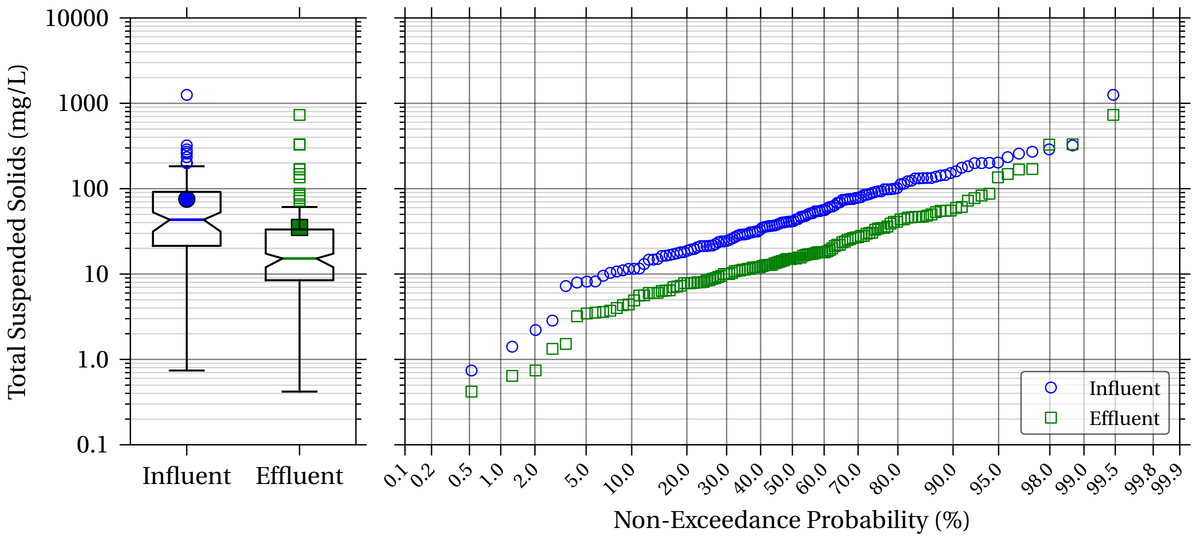


Figure 9.1: Box and Probability Plots of Total Suspended Solids at Wetland Basin BMPs

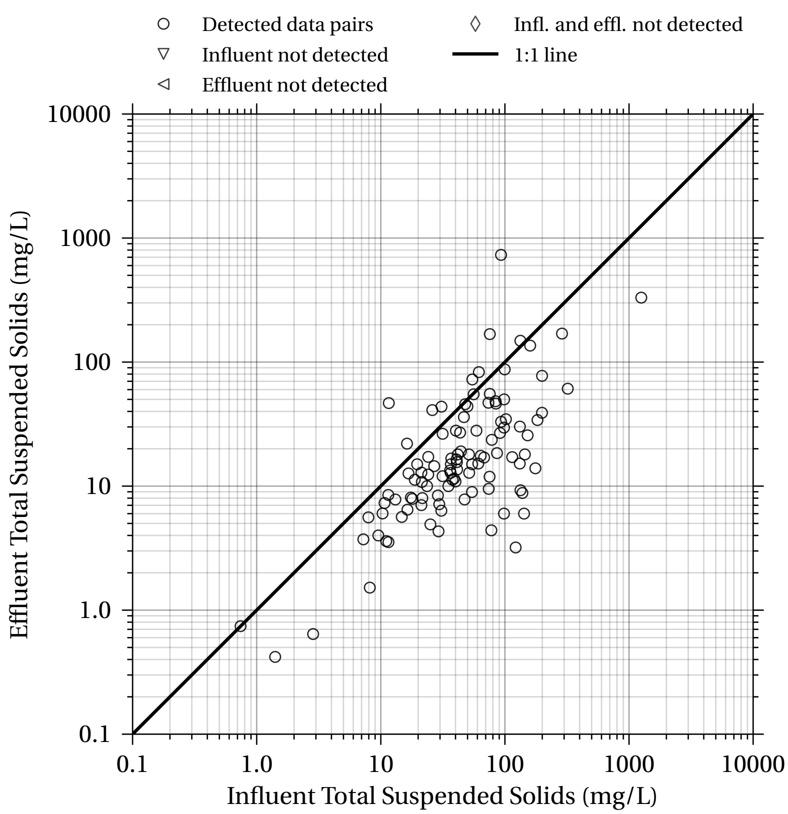


Figure 9.2: Influent vs. Effluent Plots of Total Suspended Solids at Wetland Basin BMPs

International Stormwater Best Management Practices (BMP) Database

Attachment 2:

Statistical Summary Report for Nutrients Chesapeake Bay and Related Areas

Prepared by
Geosyntec Consultants, Inc.
Wright Water Engineers, Inc.

Under Support From
National Fish and Wildlife Foundation
Water Environment Research Foundation

May 2012

Contents

1 Description of Statistics Used in this Report

This report provides a concise statistical summary of BMP performance data contained in the International Stormwater BMP Database. The analysis focuses on the distribution of effluent water quality from individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of data points reported. In other words, the performance analysis presented in this technical summary is "storm-weighted", as opposed to "BMP weighted"[1].

The statistical summaries have been organized by BMP and then by constituent. For each data set, influent and effluent summary statistics are presented in a table followed by graphical summaries.

1.1 Tabular Summaries

The summary tables include both parametric and non-parametric statistics. Parametric statistics operate under the assumption that data arise from a single statistical distribution that can be described mathematically using coefficients, or parameters, of that distribution. The mean and standard deviation are example parameters of the normal, or Gaussian, distribution. Non-parametric statistics are fundamentally based on the ranks[2] of the data with no need to assume an underlying distribution. Non-parametric statistics do not depend on the magnitude of the data and are therefore resistant to the occurrence of a few extreme values (i.e., high or low values relative to other data points do not significantly alter the statistic)[3].

Table 1.1 summarizes the parametric and non-parametric statistics commonly used to describe data sets. Definitions for each summary statistic included in the tables are provided in Table 1.2.

Table 1.1: Example Common Parametric and Non-Parametric Descriptive Statistics

Statistic Category	Parametric	Non-Parametric
Measures of Location	Mean	Median
Measures of Spread	Variance, Standard Deviation	Interquartile Range, Median Absolute Deviation
Measures of Skew	Coefficient of Skewness	Quartile Skew Coefficient

1.2 Graphical Summaries

In addition to the summary tables provided for each BMP/constituent combination, influent/effluent box plots and non-exceedance probability plots are provided. Box plots (or box and whisker plots) provide a schematic representation of the central tendency and spread of the influent and effluent data sets. Box plots can also be

[1] There are several viable approaches to evaluating the BMP Database. Two general approaches that have been presented in the past (Geosyntec and WWE 2008) are the "BMP-weighted" and "storm-weighted" approaches. The BMP-weighted approach represents each BMP with one value representing the central tendency of the BMP study, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data set. The storm-weighted approach has been selected for this report.

[2] In this context, ranks refer to the positions of the data after being sorted by magnitude.

[3] Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 pages. http://pubs.usgs.gov/twri/twri4a3/

used to indicate whether the influent median is statistically different than the effluent median. A key for the box plots is provided in Figure 1.1.

Probability plots illustrate the empirical distribution of the data. A comparison of the influent and effluent probability plots indicates whether there may be differences among all percentiles (not just the median) and whether the influent and effluent data sets are similarly distributed. Probability plots also provide a quick method of identifying the probability that an individual sample would be less than or equal to a particular value. For example, the effluent probability plot may be used to identify the probability that a particular water quality threshold would be met (e.g., 40% chance that effluent concentration would be less than or equal to 1 mg/L). It should be noted, however, that there is not a one-to-one correlation between the percentiles in the influent data and the percentiles in the effluent data. For example, the median influent concentration and the median effluent concentrations may not occur in the EMC samples collected during the same storm. Although the influent and effluent concentrations in a probability plot are not paired values, the relative position and slope of the two populations are a good indication of the effectiveness of the BMP. When generating the probability plots, the detection limits were used for non-detect values (i.e., ROS estimates or half the DL were not used). Non-detects are depicted as triangles pointing down for influent data and pointing up for effluent data.

Influent vs. effluent scatterplots depict paired data to provide an indication of how effluent concentrations may be related to the influent concentrations. Data points below the 45 degree line indicate removals whereas data points above the 45 degree line indicate increases. Detection limits are shown for non-detect values. If both the influent and effluent are non-detect, then a diamond symbol is used. If only the effluent is non-detect then a triangle symbol pointing up is used. If only the influent is non-detect, then a triangle symbol pointing down is used.

Table 1.2: Common Parametric and Non-Parametric Descriptive Statistics

Statistic	Definition/Description
Count	Total number of data points analyzed. Most BMP data sets include only event mean concentrations (EMCs). The exception includes BMPs with permanent pools (retention ponds and wetland basins) where grab samples were also included.
Number of Non-detects	The number of censored values that were reported below the analytical detection limits. Laboratory estimated values (i.e., “J” values) were treated as detected values. The plotting position, or regression-on-order statistics (ROS), method described in Helsel and Cohn (1988)[4] was used to estimate censored values using the distribution of uncensored values for each study.
Mean (95% conf. interval)	The mean of the data points and the 95% confidence interval (CI) about the mean. Provides a parametric measure of the central tendency. The confidence interval was computed using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993)[5].
Std. Dev.	The standard deviation of the data points.
Coeff. of Variation	The ratio of the standard deviation to the absolute value of the mean.
Skewness	The coefficient of skewness of the data points.

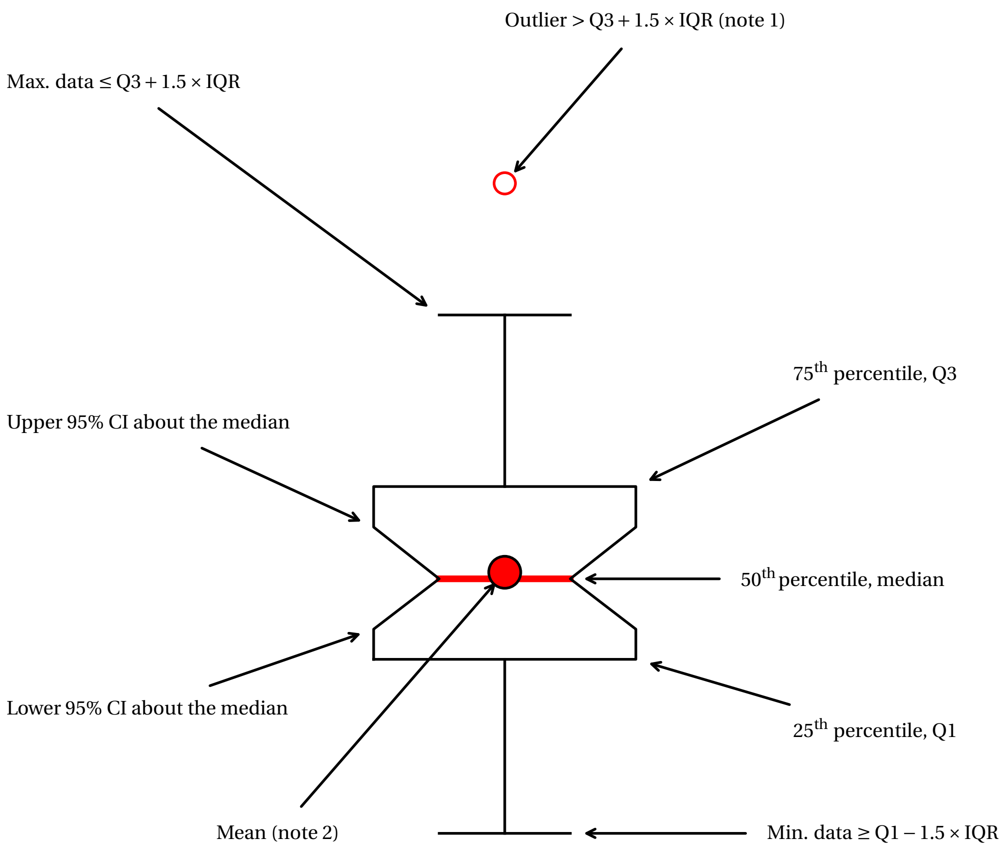
Continued on next page

Table 1.2 – continued from previous page

Statistic	Definition/Description
Median (95% conf. interval)	The median of the data points and the 95% confidence interval (CI) about the median. The confidence interval was computed using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993)[5].
25th, 75th percentiles	The difference between the 25th and 75th percentiles is the interquartile range, which is a non-parametric measure of the spread of the data.
Number of paired data	The number of storm events where influent and effluent samples were simultaneously collected.
Wilcoxon p-value	The statistical significance value for the signed-rank test, which is based on the alternative hypothesis that the median of the paired influent/effluent differences is not equal to zero. This non-parametric test applies only to paired data sets and is performed on log-transformed data (base 10) to improve the symmetry of the distribution of the differences between the data pairs. A p-value less than 0.05 indicates that the influent and effluent concentrations are statistically significantly different at the 95% confidence level.
Mann-Whitney p-value	The statistical significance value for the rank-sum test, which is based on the alternative hypothesis that the influent and effluent medians differ. This non-parametric test applies to two independent data sets. A p-value less than 0.05 indicates that the influent and effluent median concentrations are statistically significantly different at the 95% confidence level.

[4] Helsel, D.R. and T. A. Cohn (1988). "Estimation of descriptive statistics for multiply censored water quality data", *Wat. Resour. Res.* 24, 1997-2004.

[5] Efron, B. and R. Tibishirani (1993). *An Introduction to the Bootstrap.* Chapman & Hall, New York.



Notes:
1) Inner quartile range: IQR = Q3 − Q1
2) Geometric means are plotted only for bacteria data. Otherwise, arithmetic means are shown.

Boxplot Key

Figure 1.1: Graphical explanation of box and whisker plots

2 Grass Strip

2.1 Total Kjeldahl Nitrogen

Table 2.1: Summary of Total Kjeldahl Nitrogen at Grass Strip BMPs

Statistic	Inlet	Outlet
Count	130	114
Number of Non-detects	0	0
Number of Studies	7	7
Min, Max (mg/L)	0.27, 3.2	0.191, 4.43
Mean (mg/L) (95% confidence interval)	1.12 (1.01, 1.24)	1.12 (0.974, 1.27)
Standard Deviation (mg/L)	0.671	0.801
Geometric Mean (mg/L) (95% confidence interval)	0.941 (0.85, 1.05)	0.918 (0.824, 1.03)
Geometric Standard Deviation (mg/L)	1.81	1.84
Coefficient of Variation	0.602	0.724
Skewness	1.01	2.0
Median (mg/L) (95% confidence interval)	0.908 (0.76, 1.05)	0.93 (0.777, 1.04)
25^{th}, 75^{th} percentiles (mg/L)	0.589, 1.57	0.608, 1.22
Number of data pairs	114	
Wilcoxon p-value	0.471	
Mann-Whitney p-value	0.708	

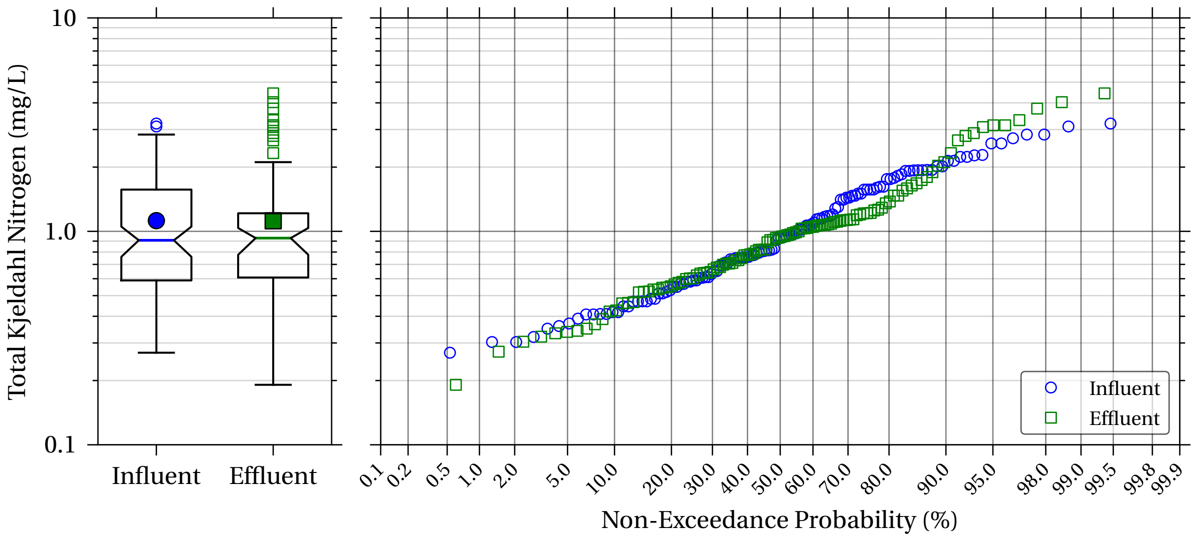


Figure 2.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Grass Strip BMPs

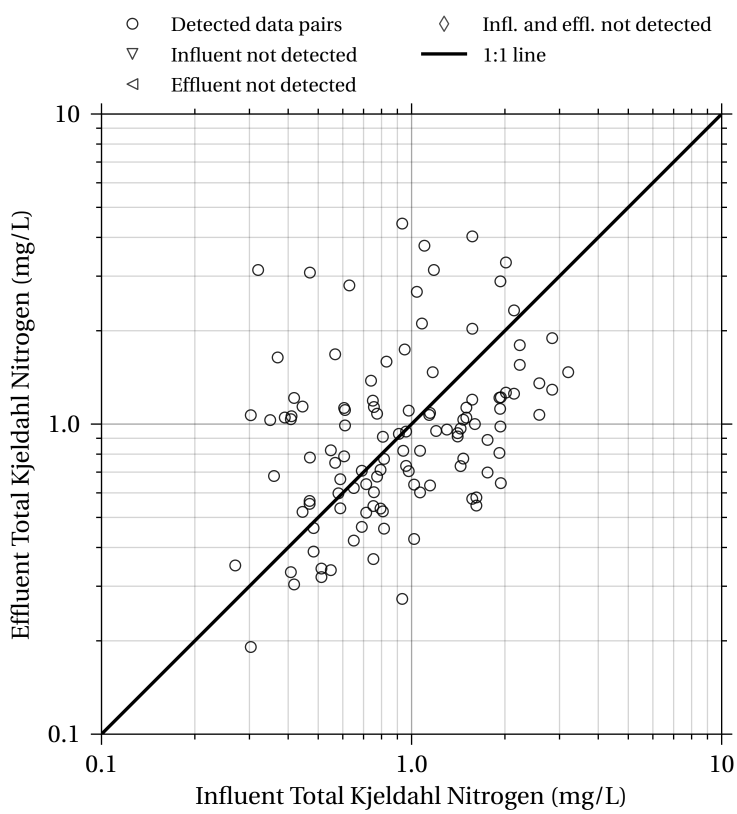


Figure 2.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Grass Strip BMPs

2.2 Ammonia as Nitrogen

Table 2.2: Summary of Ammonia as Nitrogen at Grass Strip BMPs

Statistic	**Inlet**	**Outlet**
Count	87	86
Number of Non-detects	0	0
Number of Studies	5	5
Min, Max (mg/L)	0.029, 0.636	0.013, 1.0
Mean (mg/L) (95% confidence interval)	0.179 (0.152, 0.208)	0.189 (0.148, 0.229)
Standard Deviation (mg/L)	0.133	0.193
Geometric Mean (mg/L) (95% confidence interval)	0.139 (0.12, 0.162)	0.127 (0.107, 0.154)
Geometric Standard Deviation (mg/L)	2.06	2.38
Coefficient of Variation	0.749	1.04
Skewness	1.62	2.41
Median (mg/L) (95% confidence interval)	0.148 (0.107, 0.177)	0.123 (0.102, 0.142)
25^{th}, 75^{th} percentiles (mg/L)	0.0855, 0.228	0.0763, 0.239
Number of data pairs	86	
Wilcoxon p-value	0.070	
Mann-Whitney p-value	0.408	

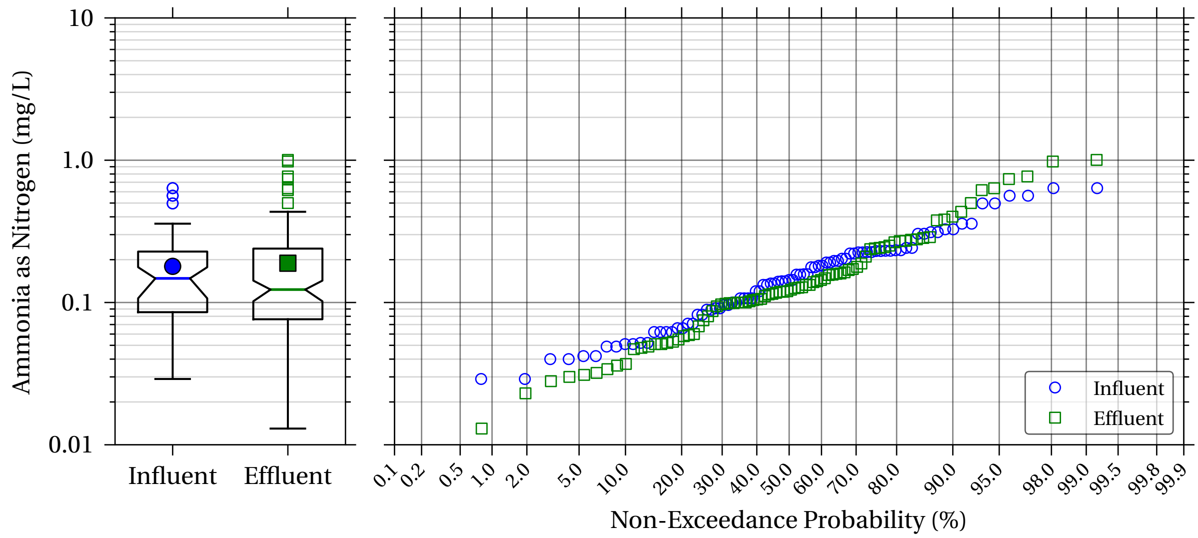


Figure 2.3: Box and Probability Plots of Ammonia as Nitrogen at Grass Strip BMPs

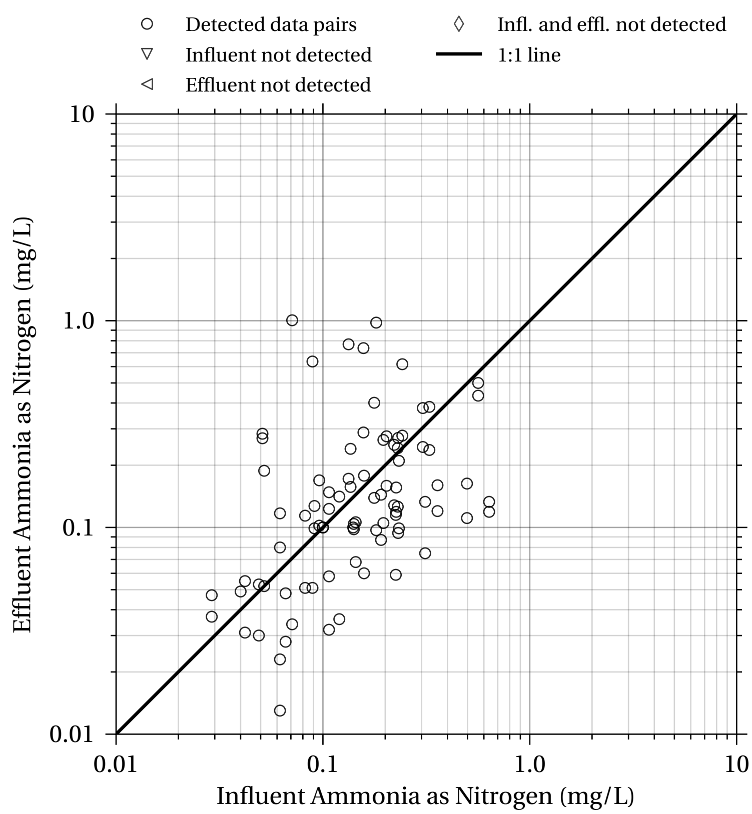


Figure 2.4: Influent vs. Effluent Plots of Ammonia as Nitrogen at Grass Strip BMPs

2.3 Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen

Table 2.3: Summary of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Grass Strip BMPs

Statistic	**Inlet**	**Outlet**
Count	132	116
Number of Non-detects	0	1
Number of Studies	7	7
Min, Max (mg/L)	0.017, 3.77	0.009, 1.59
Mean (mg/L) (95% confidence interval)	0.414 (0.324, 0.506)	0.251 (0.211, 0.294)
Standard Deviation (mg/L)	0.528	0.229
Geometric Mean (mg/L) (95% confidence interval)	0.244 (0.207, 0.293)	0.176 (0.149, 0.207)
Geometric Standard Deviation (mg/L)	2.7	2.46
Coefficient of Variation	1.29	0.923
Skewness	3.27	2.67
Median (mg/L) (95% confidence interval)	0.246 (0.172, 0.29)	0.192 (0.175, 0.219)
25^{th}, 75^{th} percentiles (mg/L)	0.12, 0.417	0.103, 0.298
Number of data pairs	116	
Wilcoxon p-value	0.037	
Mann-Whitney p-value	0.039	

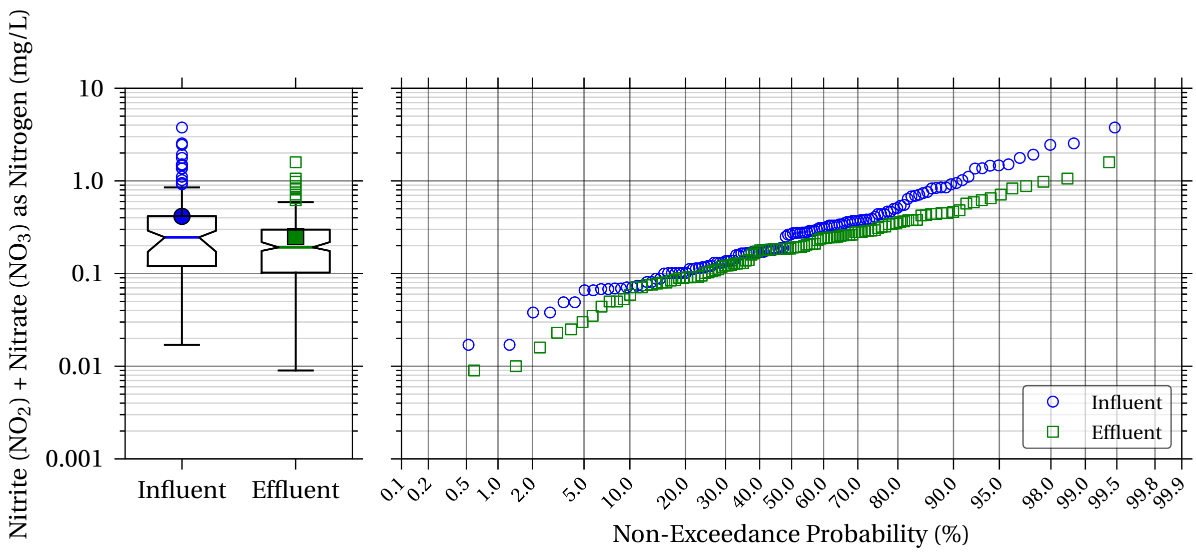


Figure 2.5: Box and Probability Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Grass Strip BMPs

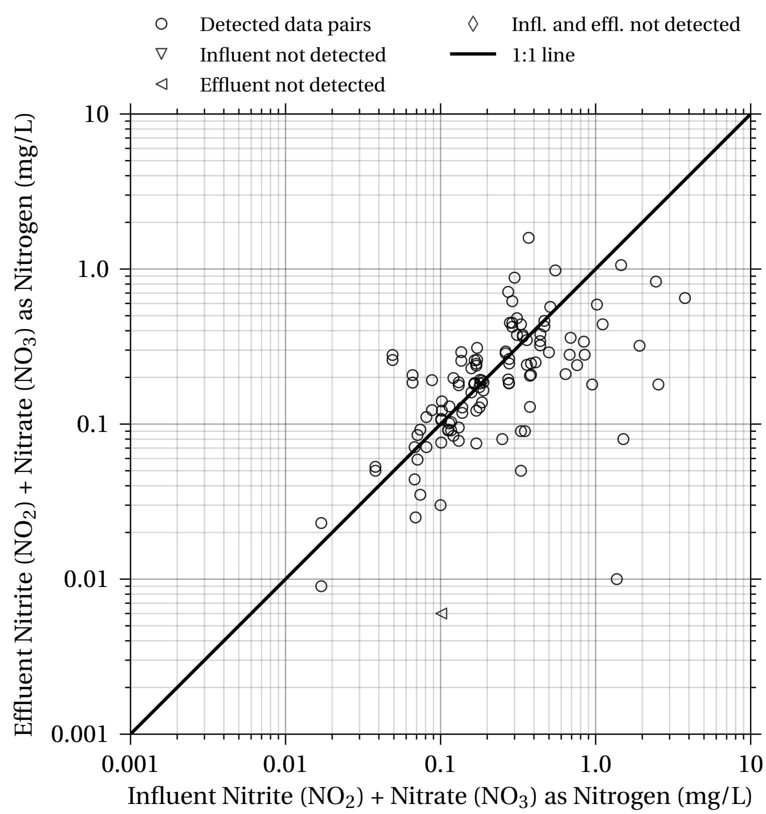


Figure 2.6: Influent vs. Effluent Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Grass Strip BMPs

2.4 NO_3 or NO_3/NO_2

Table 2.4: Summary of NO_3 or NO_3/NO_2 at Grass Strip BMPs

Statistic	Inlet	Outlet
Count	139	123
Number of Non-detects	0	1
Number of Studies	8	8
Min, Max (mg/L)	0.017, 3.77	0.009, 1.59
Mean (mg/L) (95% confidence interval)	0.398 (0.315, 0.487)	0.242 (0.203, 0.284)
Standard Deviation (mg/L)	0.518	0.225
Geometric Mean (mg/L) (95% confidence interval)	0.231 (0.195, 0.273)	0.167 (0.142, 0.197)
Geometric Standard Deviation (mg/L)	2.78	2.5
Coefficient of Variation	1.33	0.944
Skewness	3.34	2.71
Median (mg/L) (95% confidence interval)	0.232 (0.17, 0.29)	0.188 (0.16, 0.207)
25^{th}, 75^{th} percentiles (mg/L)	0.114, 0.386	0.092, 0.291
Number of data pairs	123	
Wilcoxon p-value	0.033	
Mann-Whitney p-value	0.038	

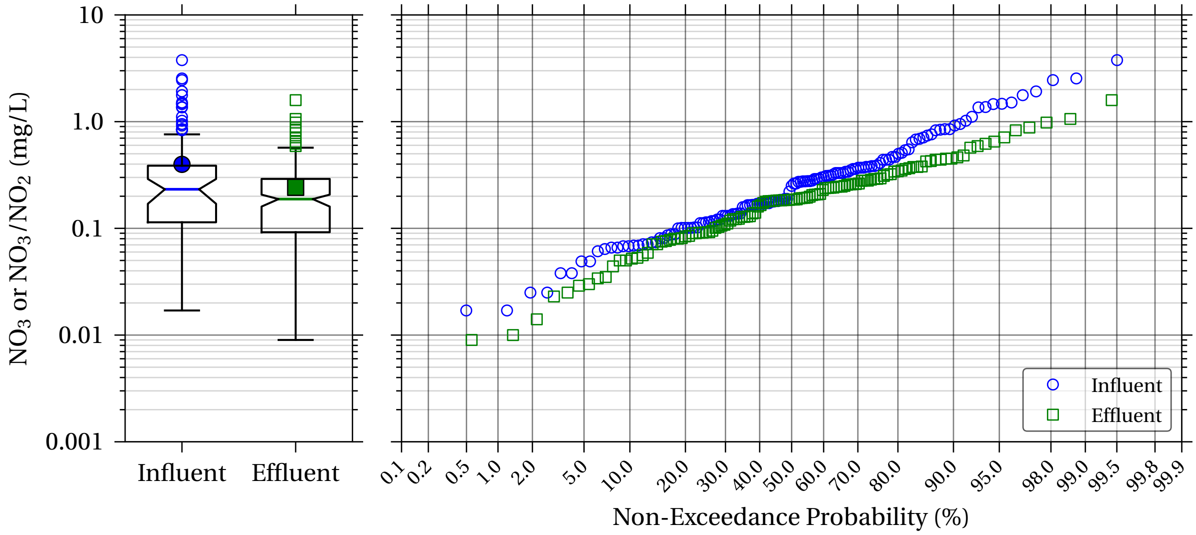


Figure 2.7: Box and Probability Plots of NO_3 or NO_3/NO_2 at Grass Strip BMPs

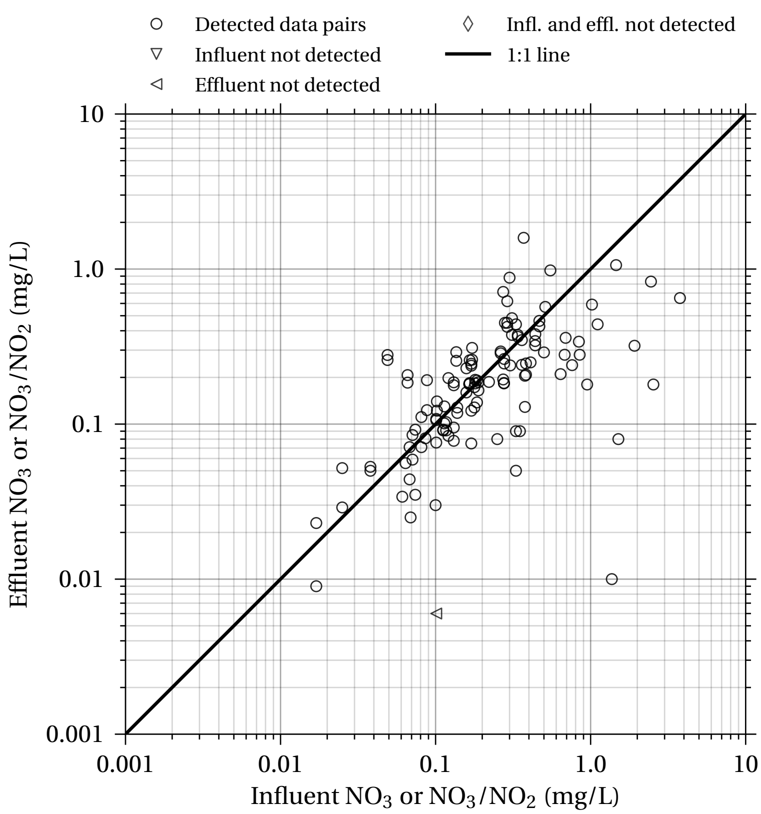


Figure 2.8: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Grass Strip BMPs

2.5 Total Nitrogen

Table 2.5: Summary of Total Nitrogen at Grass Strip BMPs

Statistic	Inlet	Outlet
Count	138	122
Number of Non-detects	0	0
Number of Studies	8	8
Min, Max (mg/L)	0.37, 4.71	0.276, 4.73
Mean (mg/L) (95% confidence interval)	1.53 (1.38, 1.68)	1.37 (1.21, 1.54)
Standard Deviation (mg/L)	0.91	0.938
Geometric Mean (mg/L) (95% confidence interval)	1.3 (1.18, 1.43)	1.14 (1.03, 1.27)
Geometric Standard Deviation (mg/L)	1.79	1.79
Coefficient of Variation	0.597	0.689
Skewness	1.18	1.91
Median (mg/L) (95% confidence interval)	1.34 (1.08, 1.51)	1.13 (0.99, 1.23)
25^{th}, 75^{th} percentiles (mg/L)	0.805, 2.04	0.8, 1.55
Number of data pairs	122	
Wilcoxon p-value	0.009	
Mann-Whitney p-value	0.070	

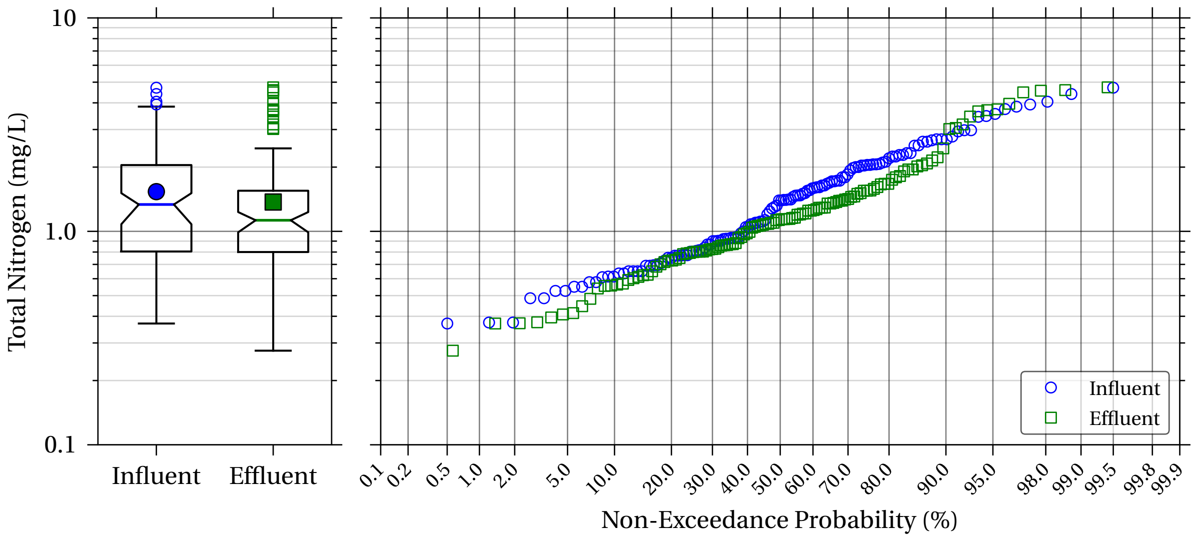


Figure 2.9: Box and Probability Plots of Total Nitrogen at Grass Strip BMPs

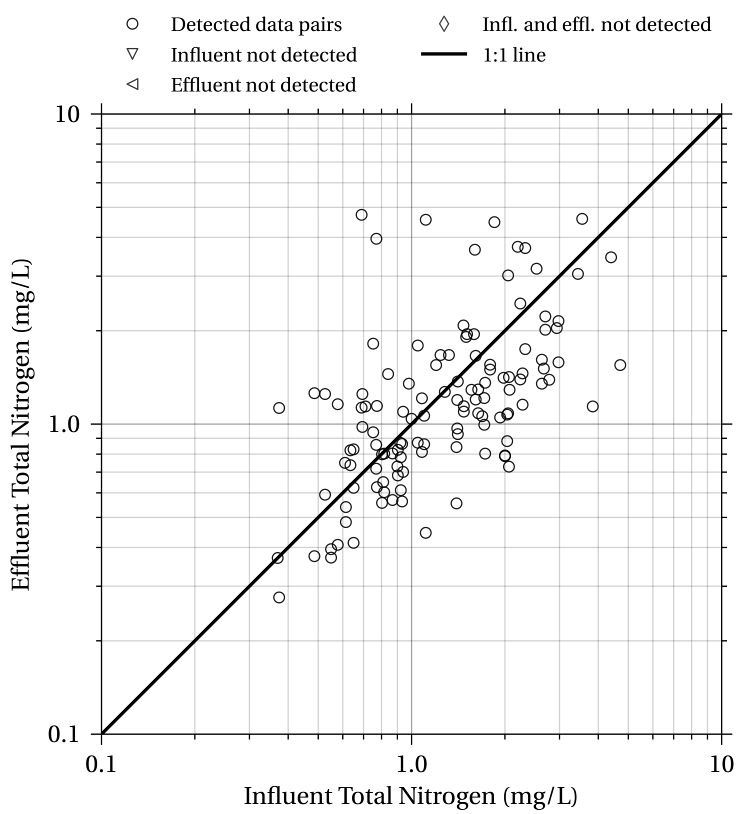


Figure 2.10: Influent vs. Effluent Plots of Total Nitrogen at Grass Strip BMPs

2.6 Total Phosphorus

Table 2.6: Summary of Total Phosphorus at Grass Strip BMPs

Statistic	Inlet	Outlet
Count	138	122
Number of Non-detects	0	0
Number of Studies	8	8
Min, Max (mg/L)	0.02, 0.45	0.044, 1.8
Mean (mg/L) (95% confidence interval)	0.152 (0.137, 0.168)	0.21 (0.175, 0.249)
Standard Deviation (mg/L)	0.0925	0.205
Geometric Mean (mg/L) (95% confidence interval)	0.125 (0.112, 0.139)	0.16 (0.142, 0.181)
Geometric Standard Deviation (mg/L)	1.93	1.98
Coefficient of Variation	0.612	1.0
Skewness	0.944	4.23
Median (mg/L) (95% confidence interval)	0.126 (0.1, 0.15)	0.157 (0.124, 0.173)
25^{th}, 75^{th} percentiles (mg/L)	0.081, 0.22	0.0973, 0.231
Number of data pairs	122	
Wilcoxon p-value	0.078	
Mann-Whitney p-value	0.026	

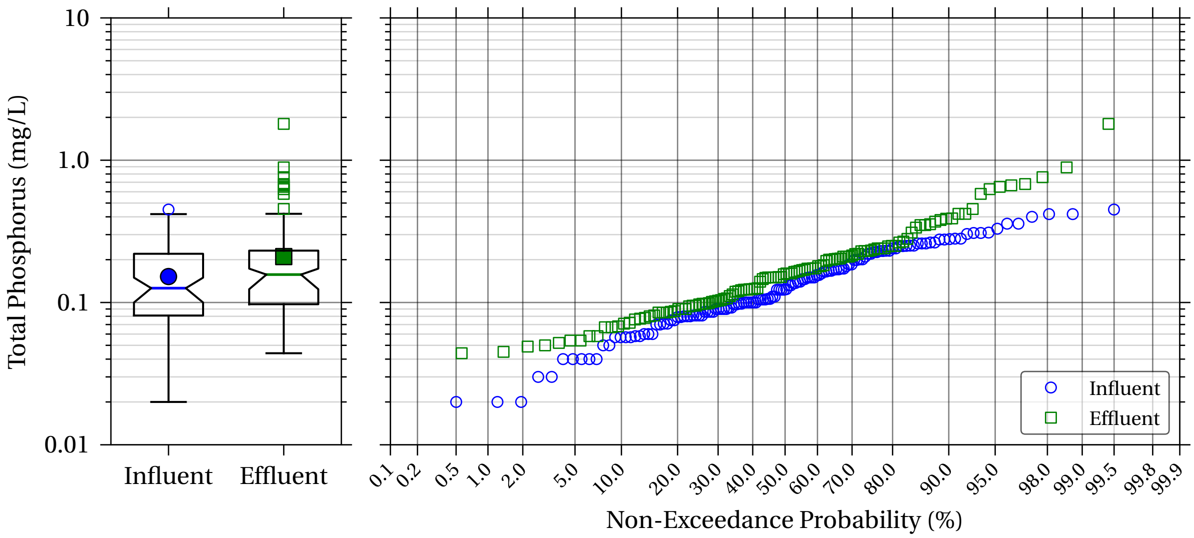


Figure 2.11: Box and Probability Plots of Total Phosphorus at Grass Strip BMPs

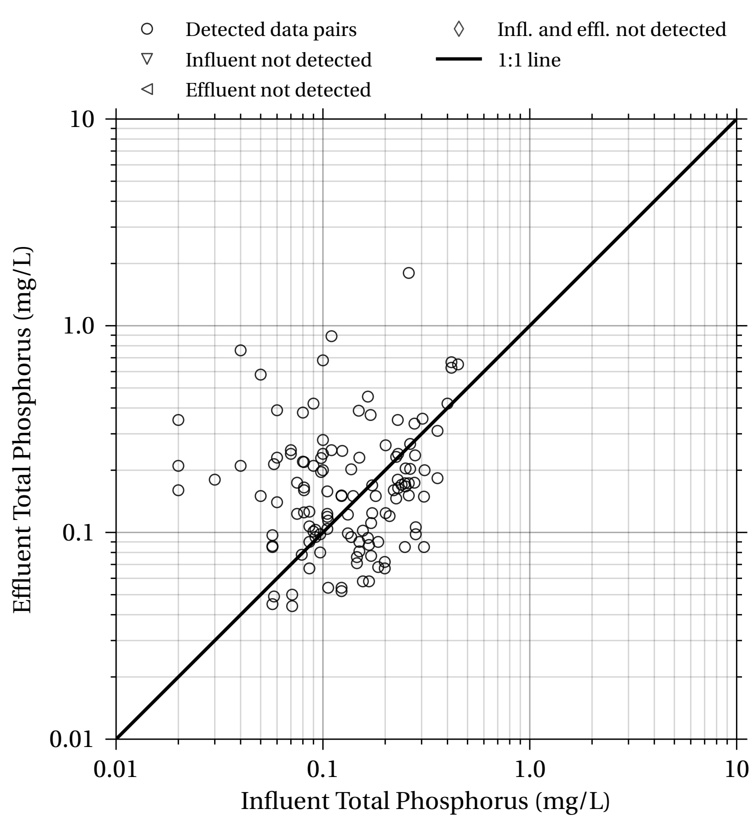


Figure 2.12: Influent vs. Effluent Plots of Total Phosphorus at Grass Strip BMPs

2.7 Orthophosphate

Table 2.7: Summary of Orthophosphate at Grass Strip BMPs

Statistic	Inlet	Outlet
Count	90	89
Number of Non-detects	20	17
Number of Studies	5	5
Min, Max (mg/L)	0.000961, 0.337	0.00114, 0.57
Mean (mg/L) (95% confidence interval)	0.052 (0.037, 0.0672)	0.065 (0.0451, 0.0864)
Standard Deviation (mg/L)	0.0714	0.0979
Geometric Mean (mg/L) (95% confidence interval)	0.0204 (0.015, 0.0278)	0.0245 (0.0177, 0.0333)
Geometric Standard Deviation (mg/L)	4.31	4.57
Coefficient of Variation	1.39	1.55
Skewness	2.13	3.37
Median (mg/L) (95% confidence interval)	0.023 (0.012, 0.032)	0.0329 (0.009, 0.045)
25^{th}, 75^{th} percentiles (mg/L)	0.007, 0.0615	0.007, 0.088
Number of data pairs	89	
Wilcoxon p-value	0.043	
Mann-Whitney p-value	0.447	

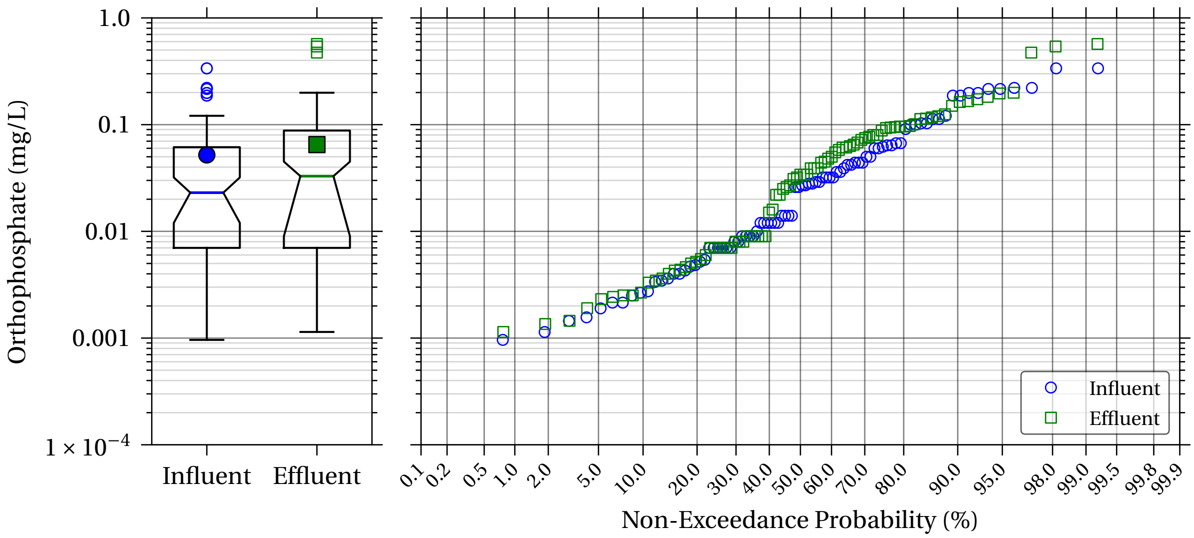


Figure 2.13: Box and Probability Plots of Orthophosphate at Grass Strip BMPs

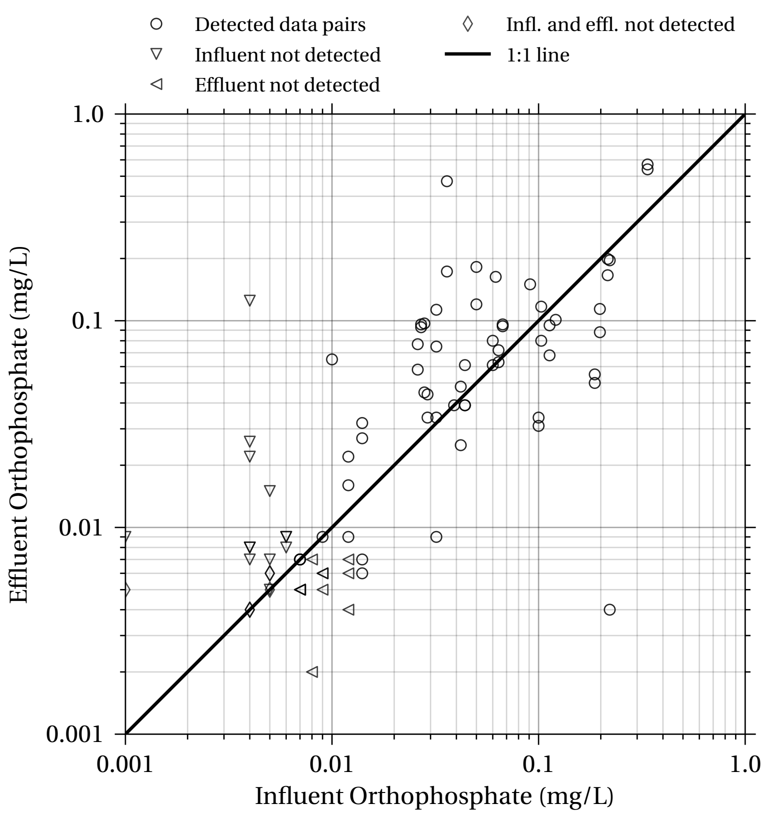


Figure 2.14: Influent vs. Effluent Plots of Orthophosphate at Grass Strip BMPs

3 Bioretention

3.1 Total Kjeldahl Nitrogen

Table 3.1: Summary of Total Kjeldahl Nitrogen at Bioretention BMPs

Statistic	**Inlet**	**Outlet**
Count	214	201
Number of Non-detects	0	5
Number of Studies	14	14
Min, Max (mg/L)	0.05, 22.0	0.003, 18.0
Mean (mg/L) (95% confidence interval)	1.41 (1.18, 1.67)	1.47 (1.14, 1.82)
Standard Deviation (mg/L)	1.81	2.42
Geometric Mean (mg/L) (95% confidence interval)	0.967 (0.867, 1.08)	0.683 (0.579, 0.803)
Geometric Standard Deviation (mg/L)	2.25	3.31
Coefficient of Variation	1.34	1.67
Skewness	6.8	3.85
Median (mg/L) (95% confidence interval)	0.936 (0.77, 1.04)	0.599 (0.463, 0.72)
25^{th}, 75^{th} percentiles (mg/L)	0.541, 1.58	0.32, 1.25
Number of data pairs	189	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

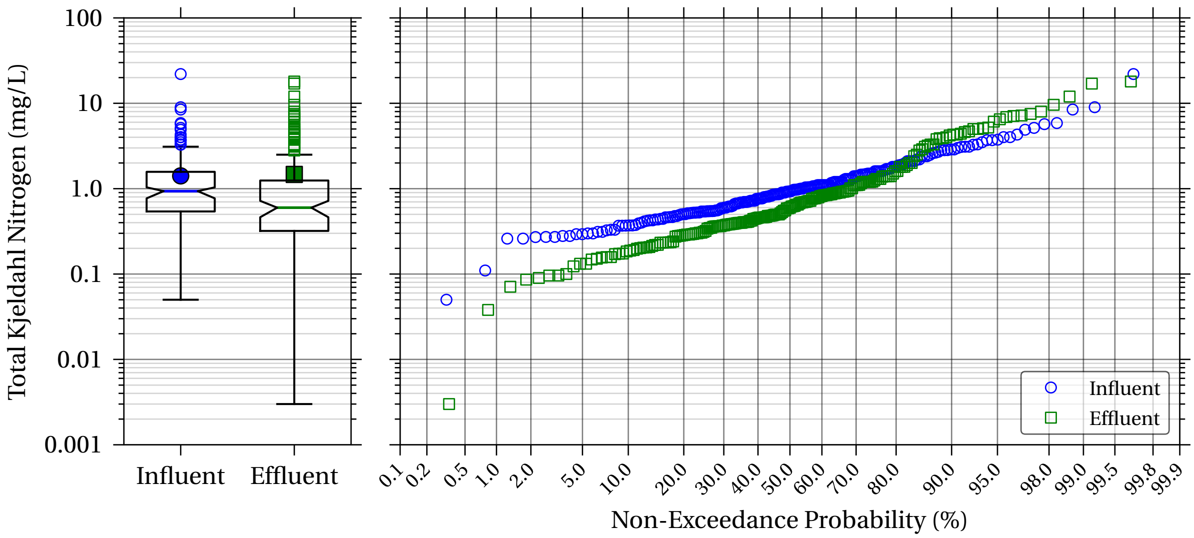


Figure 3.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Bioretention BMPs

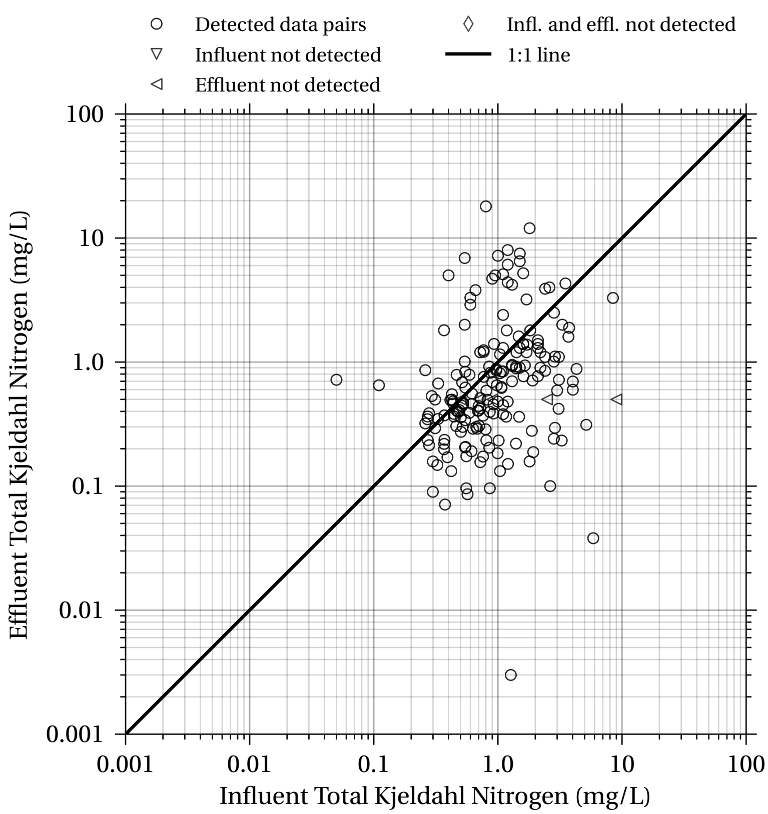


Figure 3.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Bioretention BMPs

3.2 Ammonia as Nitrogen

Table 3.2: Summary of Ammonia as Nitrogen at Bioretention BMPs

Statistic	**Inlet**	**Outlet**
Count	204	184
Number of Non-detects	11	33
Number of Studies	12	12
Min, Max (mg/L)	0.0195, 5.9	0.00221, 6.6
Mean (mg/L) (95% confidence interval)	0.385 (0.308, 0.467)	0.442 (0.302, 0.59)
Standard Deviation (mg/L)	0.569	1.01
Geometric Mean (mg/L) (95% confidence interval)	0.221 (0.192, 0.254)	0.0912 (0.0724, 0.116)
Geometric Standard Deviation (mg/L)	2.78	5.08
Coefficient of Variation	1.52	2.31
Skewness	5.53	3.11
Median (mg/L) (95% confidence interval)	0.216 (0.18, 0.25)	0.067 (0.052, 0.08)
25^{th}, 75^{th} percentiles (mg/L)	0.119, 0.441	0.0415, 0.15
Number of data pairs	174	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

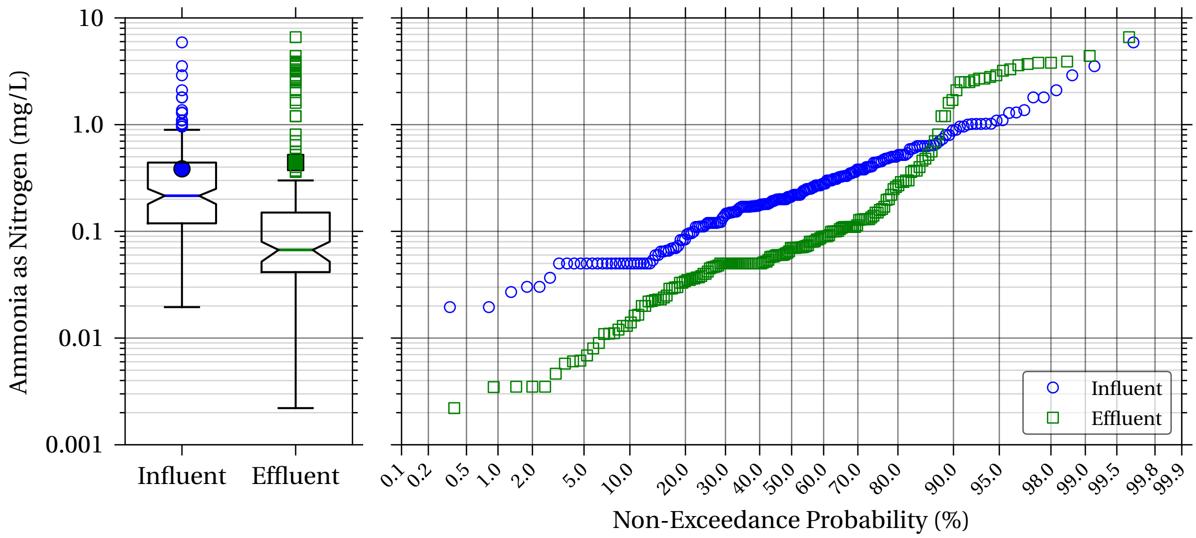


Figure 3.3: Box and Probability Plots of Ammonia as Nitrogen at Bioretention BMPs

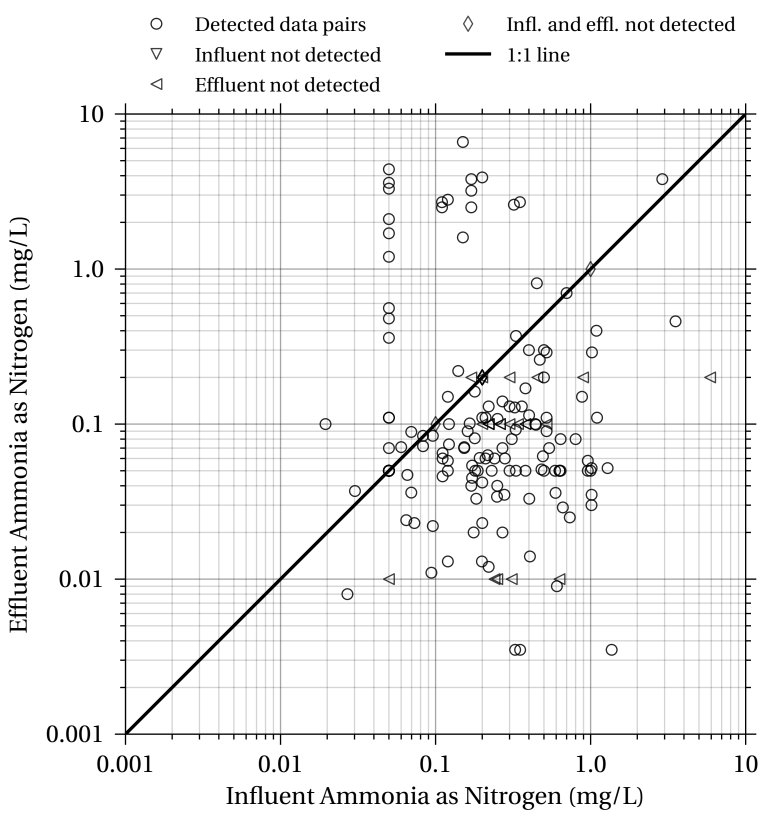


Figure 3.4: Influent vs. Effluent Plots of Ammonia as Nitrogen at Bioretention BMPs

3.3 Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen

Table 3.3: Summary of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Bioretention BMPs

Statistic	**Inlet**	**Outlet**
Count	225	211
Number of Non-detects	2	6
Number of Studies	14	14
Min, Max (mg/L)	0.03, 3.0	0.005, 4.68
Mean (mg/L) (95% confidence interval)	0.354 (0.307, 0.402)	0.398 (0.318, 0.481)
Standard Deviation (mg/L)	0.359	0.603
Geometric Mean (mg/L) (95% confidence interval)	0.256 (0.23, 0.283)	0.198 (0.169, 0.235)
Geometric Standard Deviation (mg/L)	2.23	3.44
Coefficient of Variation	1.03	1.54
Skewness	4.04	3.91
Median (mg/L) (95% confidence interval)	0.266 (0.24, 0.29)	0.223 (0.185, 0.26)
25^{th}, 75^{th} percentiles (mg/L)	0.16, 0.414	0.11, 0.392
Number of data pairs	198	
Wilcoxon p-value	0.039	
Mann-Whitney p-value	0.027	

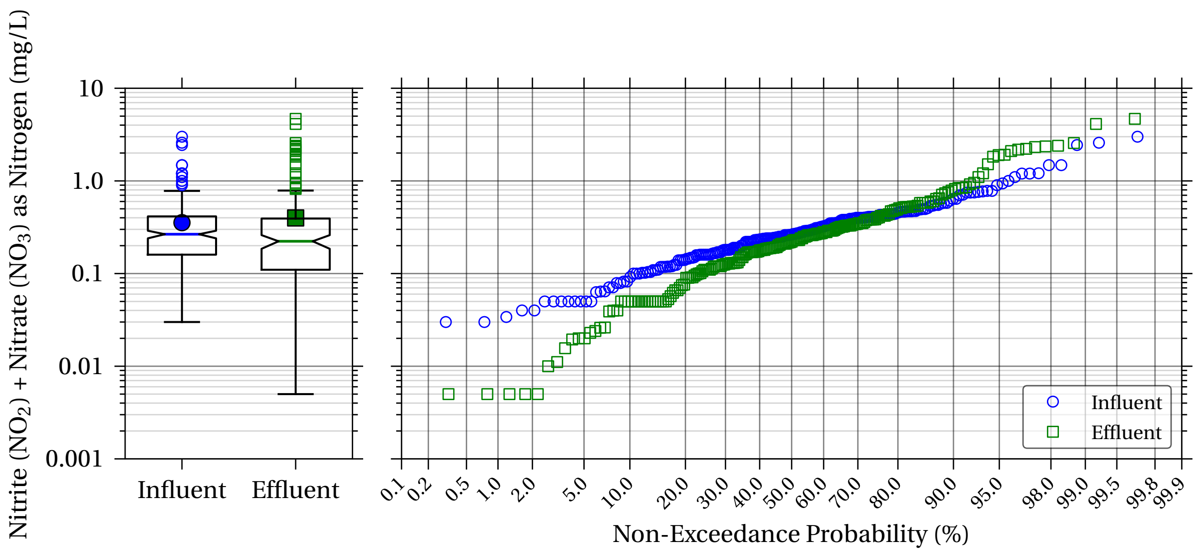


Figure 3.5: Box and Probability Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Bioretention BMPs

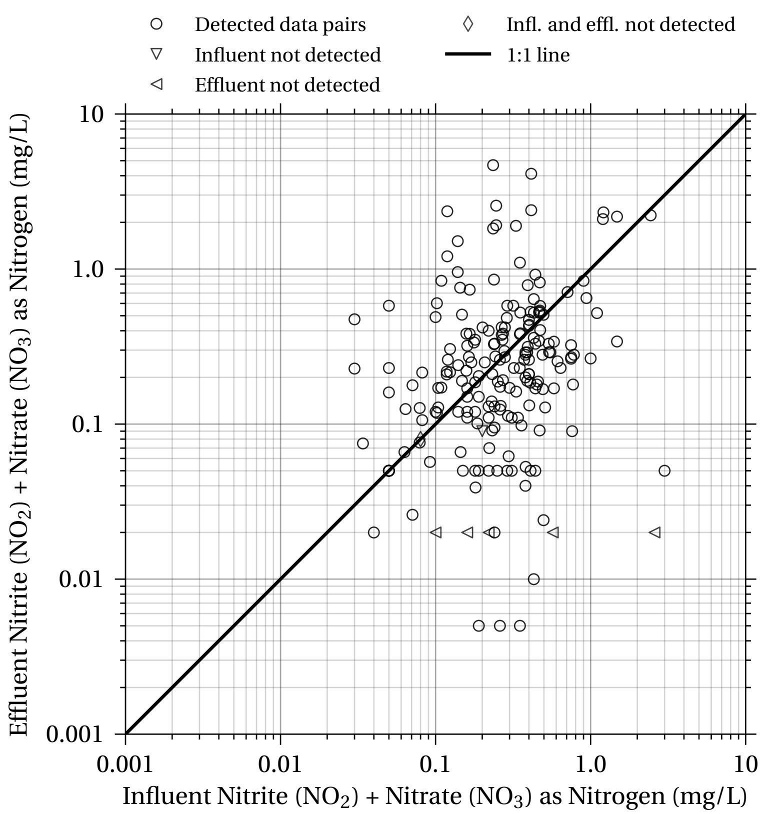


Figure 3.6: Influent vs. Effluent Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Bioretention BMPs

3.4 NO_3 or NO_3/NO_2

Table 3.4: Summary of NO_3 or NO_3/NO_2 at Bioretention BMPs

Statistic	Inlet	Outlet
Count	249	230
Number of Non-detects	2	6
Number of Studies	15	15
Min, Max (mg/L)	0.03, 3.0	0.005, 4.68
Mean (mg/L) (95% confidence interval)	0.352 (0.31, 0.397)	0.391 (0.318, 0.469)
Standard Deviation (mg/L)	0.351	0.581
Geometric Mean (mg/L) (95% confidence interval)	0.256 (0.232, 0.282)	0.204 (0.174, 0.238)
Geometric Standard Deviation (mg/L)	2.21	3.32
Coefficient of Variation	1.01	1.5
Skewness	3.99	4.05
Median (mg/L) (95% confidence interval)	0.263 (0.24, 0.29)	0.229 (0.19, 0.26)
25^{th}, 75^{th} percentiles (mg/L)	0.16, 0.41	0.114, 0.409
Number of data pairs	217	
Wilcoxon p-value	0.069	
Mann-Whitney p-value	0.049	

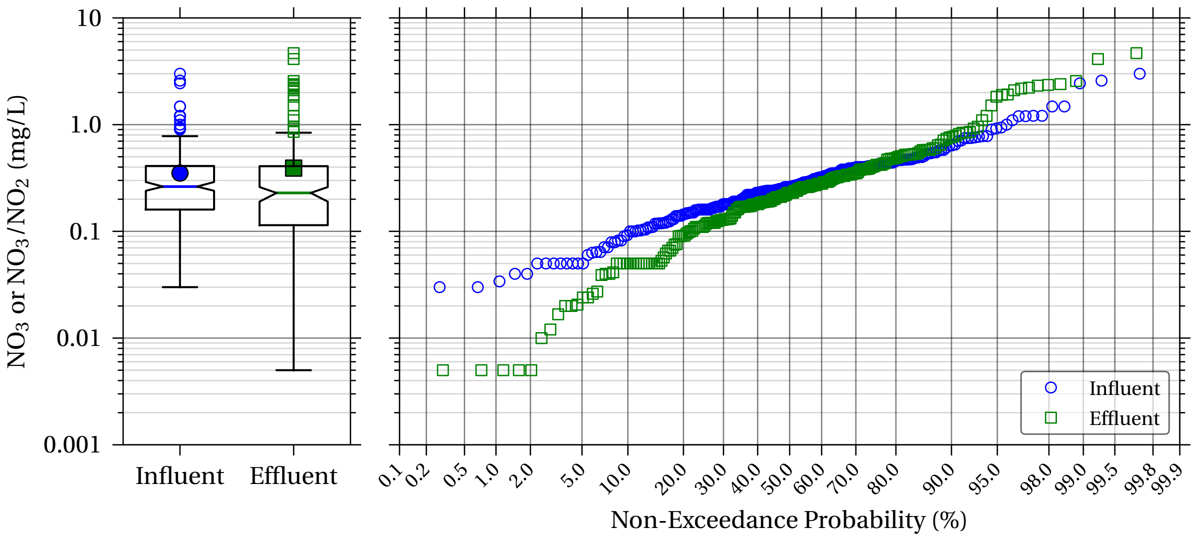


Figure 3.7: Box and Probability Plots of NO_3 or NO_3/NO_2 at Bioretention BMPs

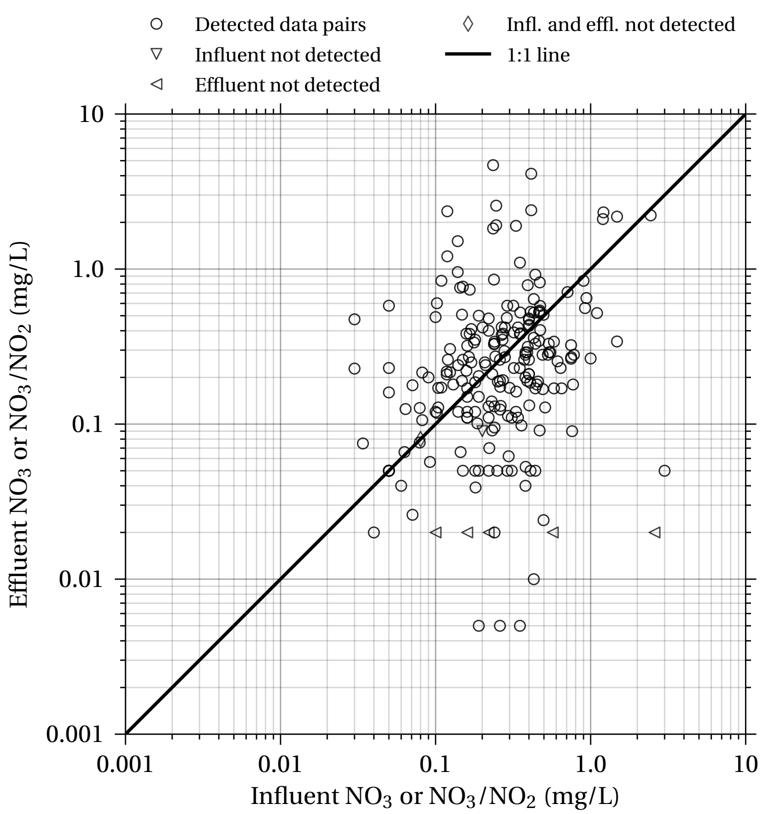


Figure 3.8: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Bioretention BMPs

3.5 Total Nitrogen

Table 3.5: Summary of Total Nitrogen at Bioretention BMPs

Statistic	Inlet	Outlet
Count	218	200
Number of Non-detects	0	0
Number of Studies	12	12
Min, Max (mg/L)	0.1, 22.3	0.09, 18.2
Mean (mg/L) (95% confidence interval)	1.67 (1.44, 1.92)	1.74 (1.41, 2.09)
Standard Deviation (mg/L)	1.74	2.46
Geometric Mean (mg/L) (95% confidence interval)	1.27 (1.15, 1.39)	0.995 (0.868, 1.14)
Geometric Standard Deviation (mg/L)	2.02	2.69
Coefficient of Variation	1.09	1.43
Skewness	7.01	3.74
Median (mg/L) (95% confidence interval)	1.25 (1.06, 1.35)	0.896 (0.74, 0.995)
25^{th}, 75^{th} percentiles (mg/L)	0.772, 1.99	0.53, 1.54
Number of data pairs	188	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

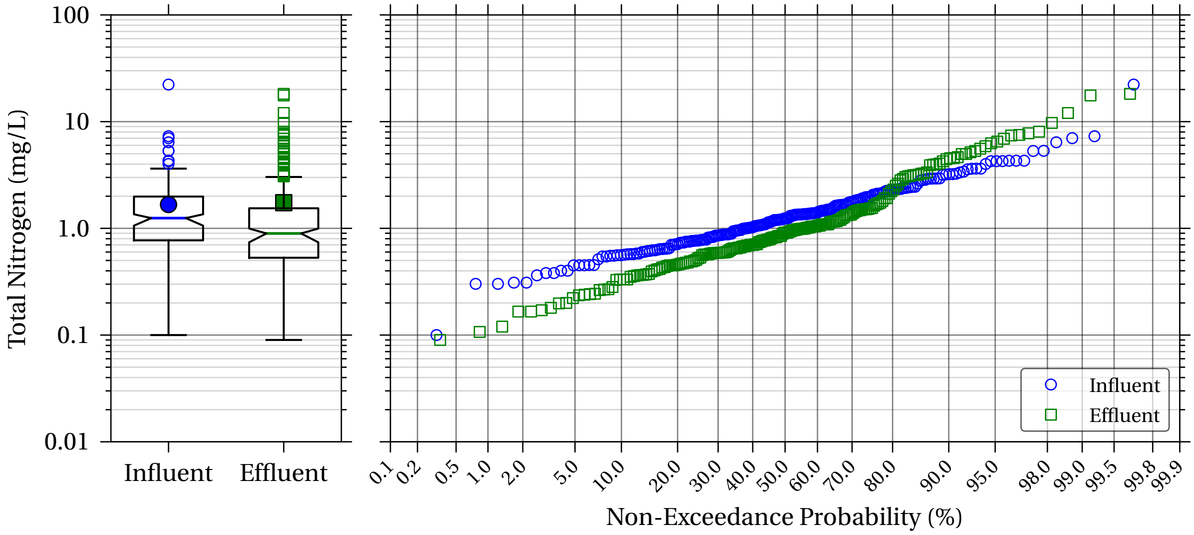


Figure 3.9: Box and Probability Plots of Total Nitrogen at Bioretention BMPs

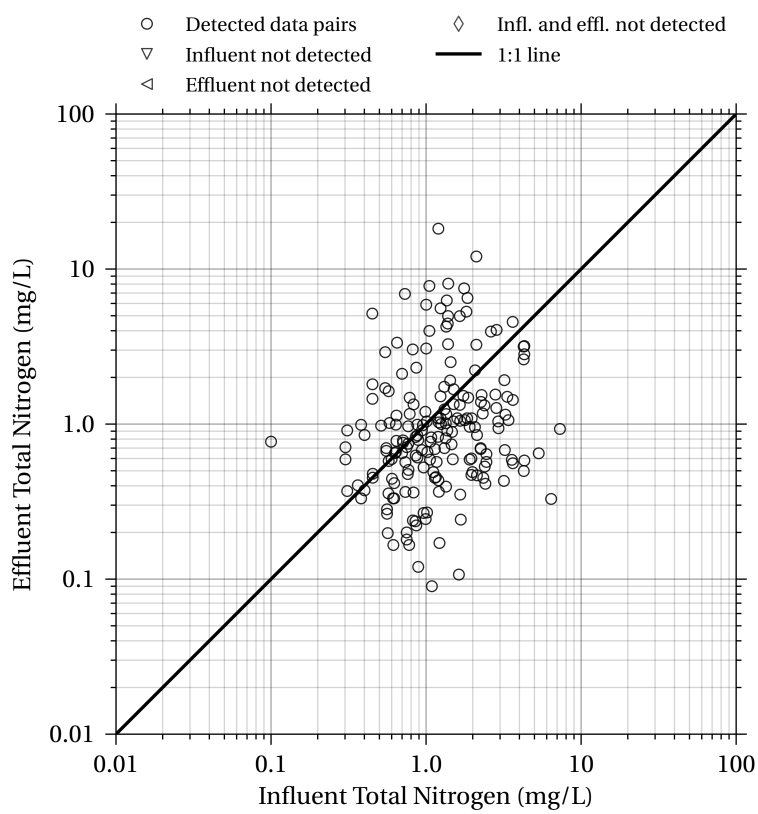


Figure 3.10: Influent vs. Effluent Plots of Total Nitrogen at Bioretention BMPs

3.6 Total Phosphorus

Table 3.6: Summary of Total Phosphorus at Bioretention BMPs

Statistic	Inlet	Outlet
Count	224	205
Number of Non-detects	0	5
Number of Studies	15	15
Min, Max (mg/L)	0.005, 1.4	0.00304, 23.1
Mean (mg/L) (95% confidence interval)	0.178 (0.148, 0.208)	0.54 (0.291, 0.836)
Standard Deviation (mg/L)	0.226	1.97
Geometric Mean (mg/L) (95% confidence interval)	0.11 (0.0971, 0.124)	0.124 (0.102, 0.151)
Geometric Standard Deviation (mg/L)	2.53	4.11
Coefficient of Variation	1.29	3.84
Skewness	3.27	8.03
Median (mg/L) (95% confidence interval)	0.104 (0.0825, 0.12)	0.0902 (0.071, 0.1)
25^{th}, 75^{th} percentiles (mg/L)	0.059, 0.2	0.049, 0.24
Number of data pairs	193	
Wilcoxon p-value	0.815	
Mann-Whitney p-value	0.920	

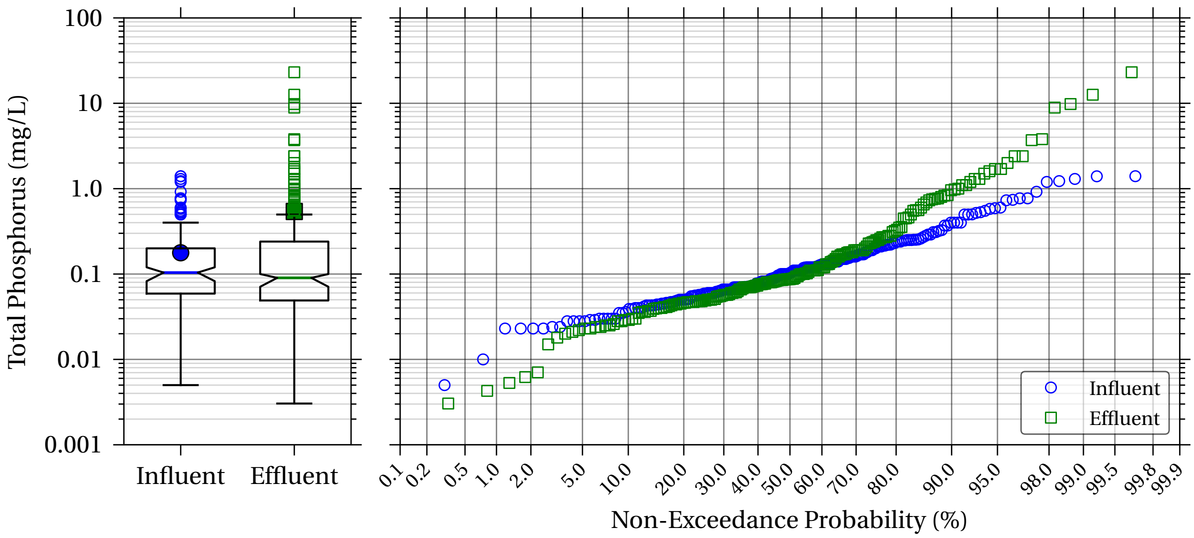


Figure 3.11: Box and Probability Plots of Total Phosphorus at Bioretention BMPs

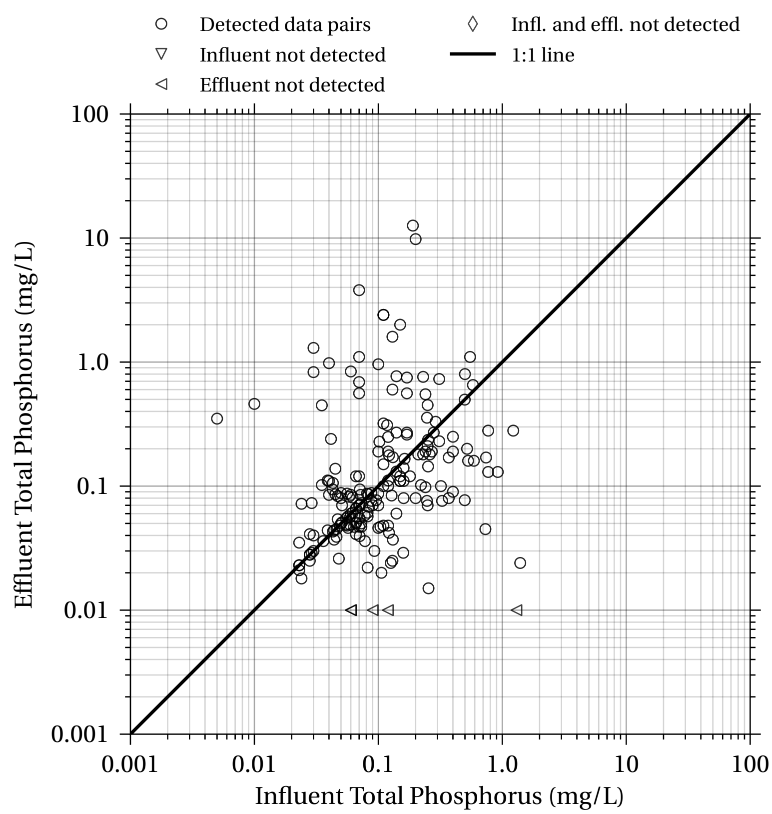


Figure 3.12: Influent vs. Effluent Plots of Total Phosphorus at Bioretention BMPs

3.7 Orthophosphate

Table 3.7: Summary of Orthophosphate at Bioretention BMPs

Statistic	Inlet	Outlet
Count	164	164
Number of Non-detects	3	6
Number of Studies	13	13
Min, Max (mg/L)	0.002, 1.1	0.00123, 21.9
Mean (mg/L) (95% confidence interval)	0.0694 (0.0469, 0.0931)	0.522 (0.241, 0.863)
Standard Deviation (mg/L)	0.149	1.97
Geometric Mean (mg/L) (95% confidence interval)	0.0182 (0.0144, 0.0231)	0.0467 (0.0341, 0.0635)
Geometric Standard Deviation (mg/L)	4.71	7.55
Coefficient of Variation	2.19	4.04
Skewness	4.01	7.59
Median (mg/L) (95% confidence interval)	0.0133 (0.009, 0.02)	0.0353 (0.016, 0.05)
25^{th}, 75^{th} percentiles (mg/L)	0.005, 0.05	0.008, 0.162
Number of data pairs	152	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

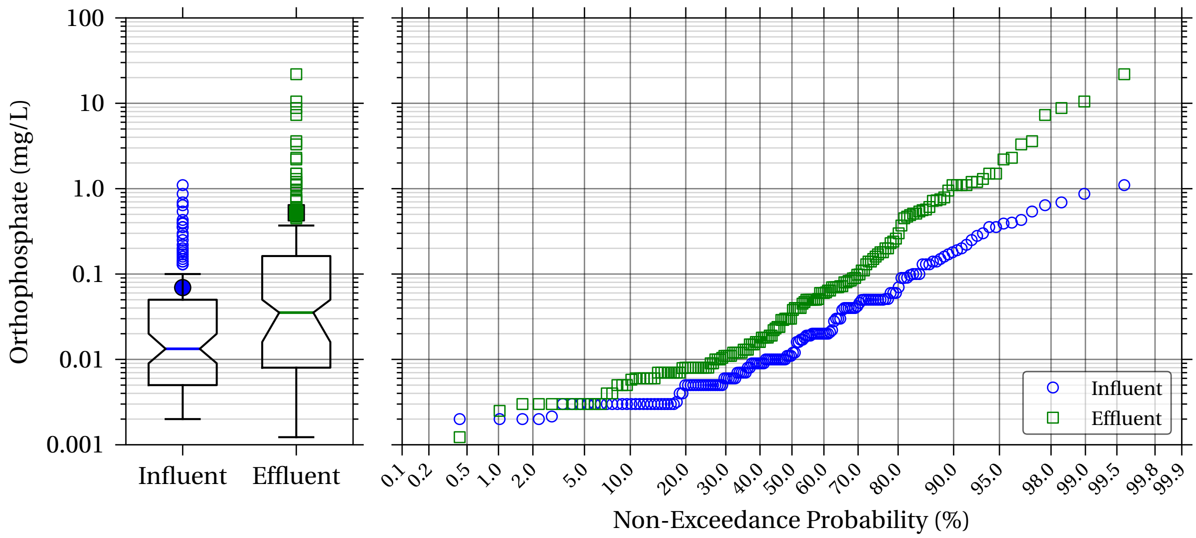


Figure 3.13: Box and Probability Plots of Orthophosphate at Bioretention BMPs

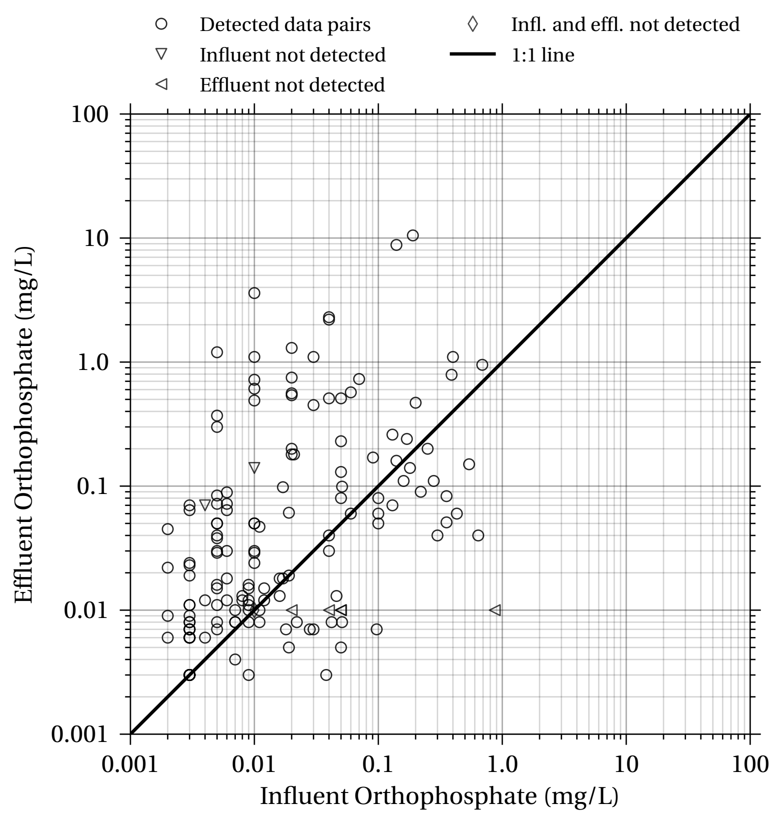


Figure 3.14: Influent vs. Effluent Plots of Orthophosphate at Bioretention BMPs

4 Detention Basin

4.1 Total Phosphorus

Table 4.1: Summary of Total Phosphorus at Detention Basin BMPs

Statistic	Inlet	Outlet
Count	55	67
Number of Non-detects	0	0
Number of Studies	6	6
Min, Max (mg/L)	0.0428, 0.859	0.0303, 0.81
Mean (mg/L) (95% confidence interval)	0.294 (0.248, 0.34)	0.213 (0.177, 0.249)
Standard Deviation (mg/L)	0.173	0.148
Geometric Mean (mg/L) (95% confidence interval)	0.245 (0.206, 0.288)	0.172 (0.147, 0.201)
Geometric Standard Deviation (mg/L)	1.85	1.9
Coefficient of Variation	0.597	0.711
Skewness	1.1	1.77
Median (mg/L) (95% confidence interval)	0.237 (0.197, 0.3)	0.167 (0.121, 0.198)
25^{th}, 75^{th} percentiles (mg/L)	0.179, 0.401	0.112, 0.286
Number of data pairs	54	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.002	

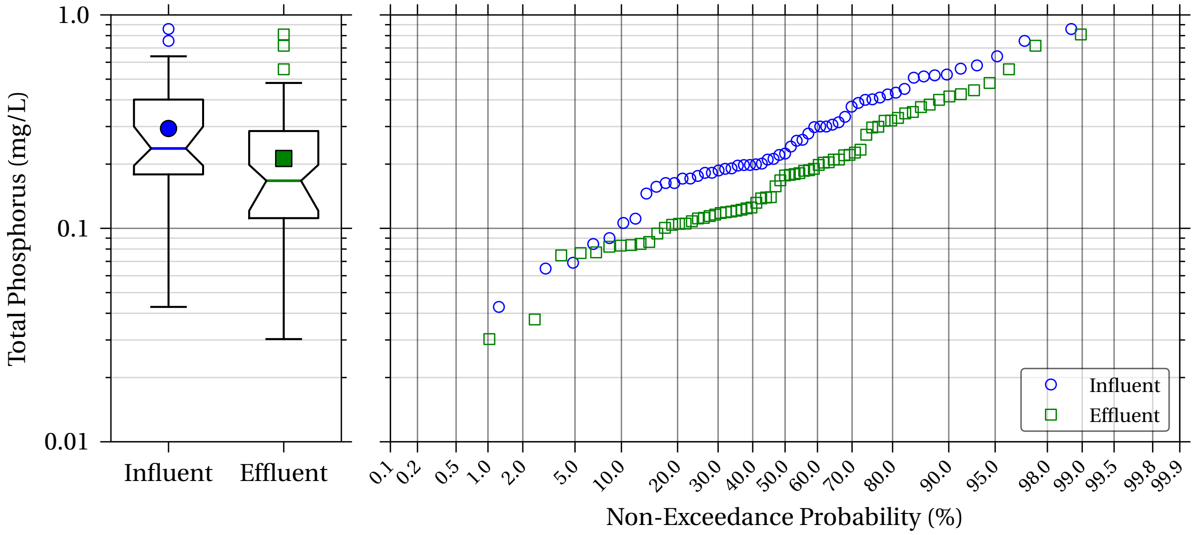


Figure 4.1: Box and Probability Plots of Total Phosphorus at Detention Basin BMPs

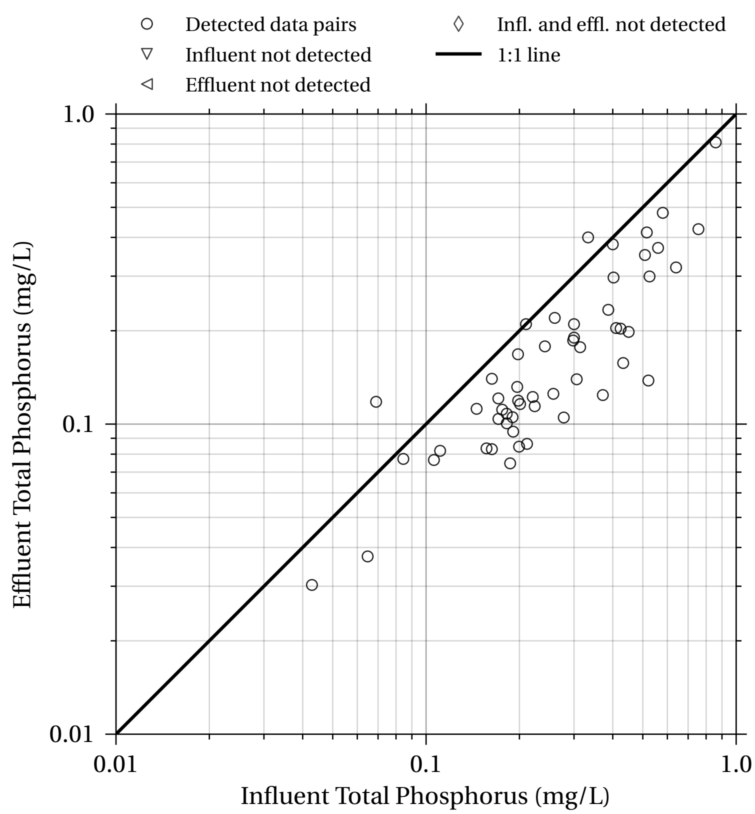


Figure 4.2: Influent vs. Effluent Plots of Total Phosphorus at Detention Basin BMPs

5 Manufactured Device

5.1 Total Kjeldahl Nitrogen

Table 5.1: Summary of Total Kjeldahl Nitrogen at Manufactured Device BMPs

Statistic	Inlet	Outlet
Count	74	74
Number of Non-detects	0	1
Number of Studies	7	7
Min, Max (mg/L)	0.2, 40.8	0.134, 12.8
Mean (mg/L) (95% confidence interval)	3.05 (2.05, 4.25)	2.21 (1.72, 2.75)
Standard Deviation (mg/L)	4.66	2.23
Geometric Mean (mg/L) (95% confidence interval)	1.81 (1.45, 2.23)	1.45 (1.18, 1.8)
Geometric Standard Deviation (mg/L)	2.53	2.51
Coefficient of Variation	1.67	1.03
Skewness	5.75	2.39
Median (mg/L) (95% confidence interval)	1.72 (1.12, 2.27)	1.45 (0.97, 1.87)
25^{th}, 75^{th} percentiles (mg/L)	0.87, 3.19	0.723, 3.12
Number of data pairs	74	
Wilcoxon p-value	0.003	
Mann-Whitney p-value	0.229	

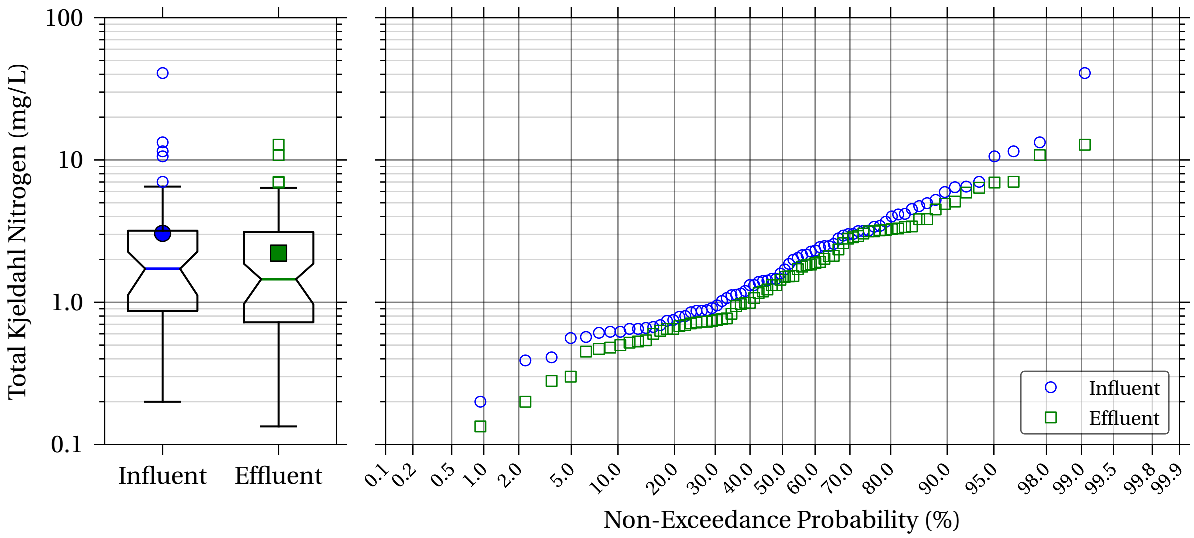


Figure 5.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Manufactured Device BMPs

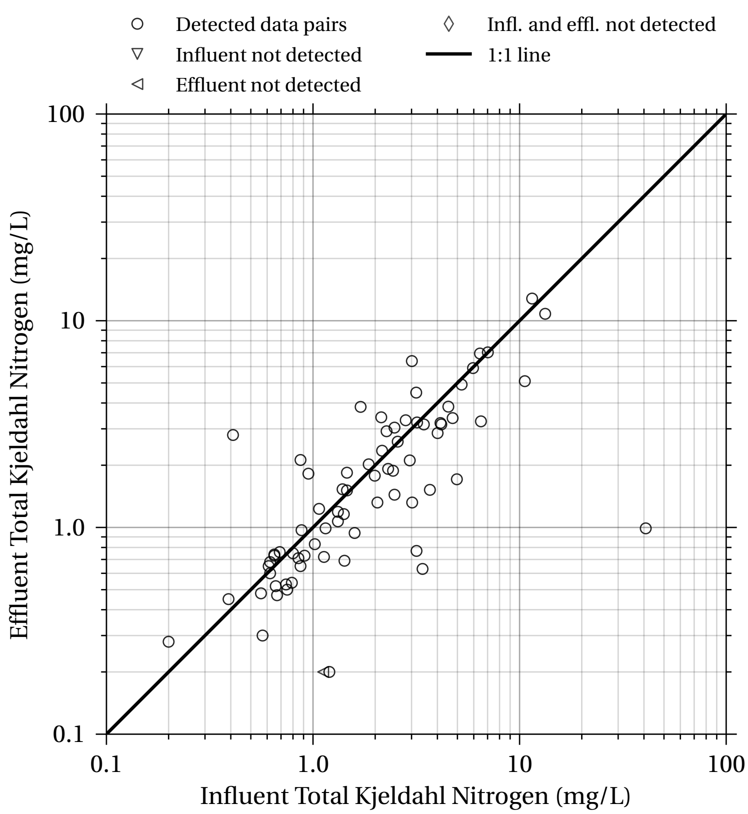


Figure 5.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Manufactured Device BMPs

5.2 Ammonia as Nitrogen

Table 5.2: Summary of Ammonia as Nitrogen at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	74	74
Number of Non-detects	31	30
Number of Studies	7	7
Min, Max (mg/L)	0.0245, 2.29	0.0213, 2.04
Mean (mg/L) (95% confidence interval)	0.418 (0.315, 0.524)	0.438 (0.331, 0.545)
Standard Deviation (mg/L)	0.457	0.466
Geometric Mean (mg/L) (95% confidence interval)	0.254 (0.202, 0.319)	0.256 (0.198, 0.326)
Geometric Standard Deviation (mg/L)	2.72	2.9
Coefficient of Variation	1.12	1.08
Skewness	2.19	1.67
Median (mg/L) (95% confidence interval)	0.254 (0.178, 0.3)	0.26 (0.174, 0.33)
25^{th}, 75^{th} percentiles (mg/L)	0.128, 0.47	0.121, 0.57
Number of data pairs	74	
Wilcoxon p-value	0.661	
Mann-Whitney p-value	0.998	

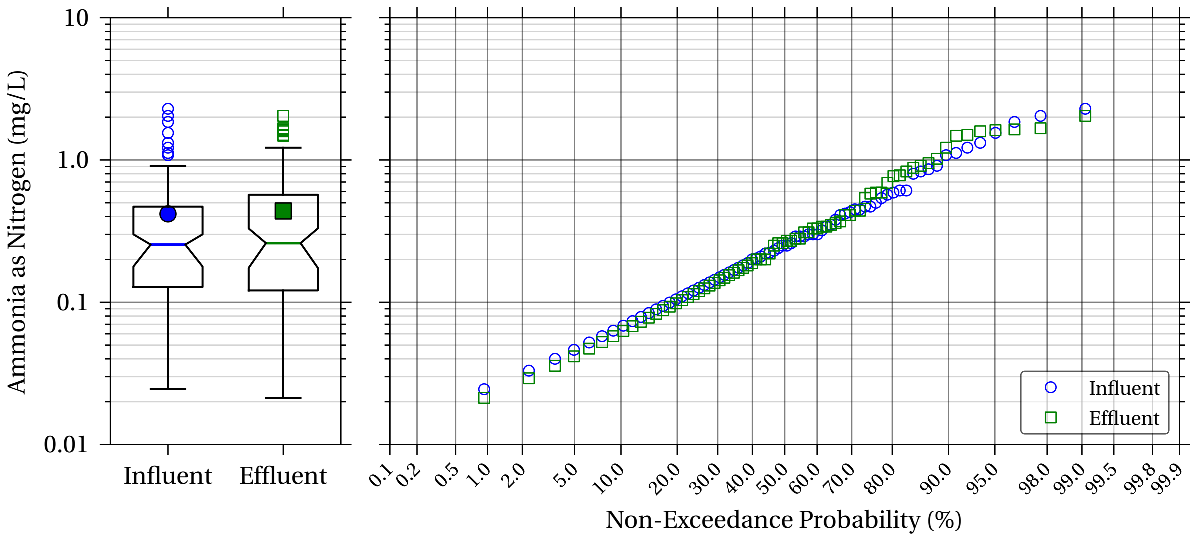


Figure 5.3: Box and Probability Plots of Ammonia as Nitrogen at Manufactured Device BMPs

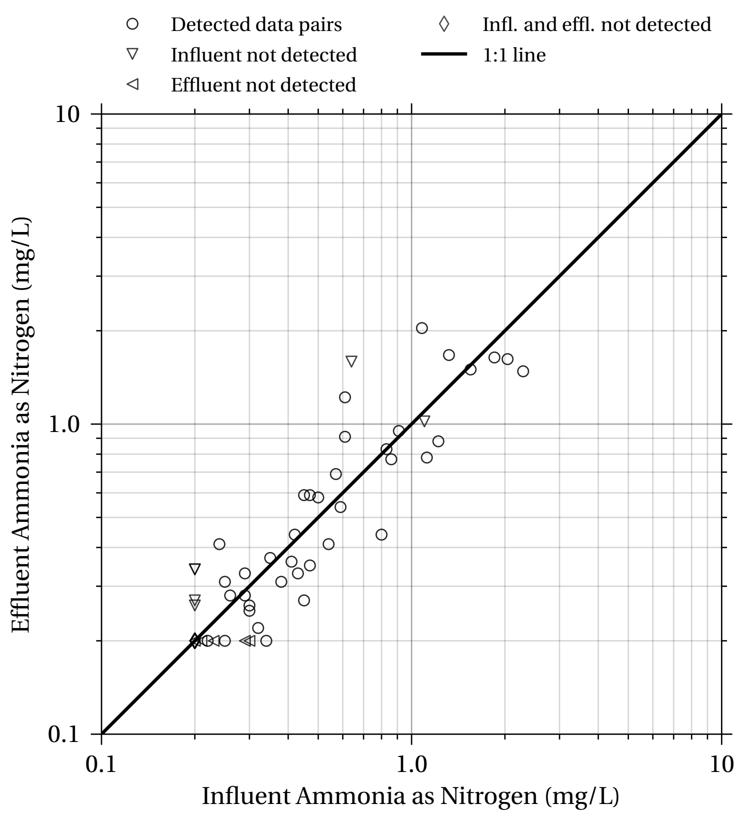


Figure 5.4: Influent vs. Effluent Plots of Ammonia as Nitrogen at Manufactured Device BMPs

5.3 Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen

Table 5.3: Summary of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	74	74
Number of Non-detects	18	22
Number of Studies	7	7
Min, Max (mg/L)	0.0478, 3.66	0.0261, 54.2
Mean (mg/L) (95% confidence interval)	0.54 (0.416, 0.66)	1.19 (0.378, 2.65)
Standard Deviation (mg/L)	0.521	5.0
Geometric Mean (mg/L) (95% confidence interval)	0.363 (0.294, 0.447)	0.325 (0.249, 0.425)
Geometric Standard Deviation (mg/L)	2.46	3.18
Coefficient of Variation	0.999	5.23
Skewness	2.99	8.37
Median (mg/L) (95% confidence interval)	0.407 (0.2, 0.5)	0.389 (0.17, 0.47)
25^{th}, 75^{th} percentiles (mg/L)	0.171, 0.73	0.133, 0.675
Number of data pairs	74	
Wilcoxon p-value	0.382	
Mann-Whitney p-value	0.401	

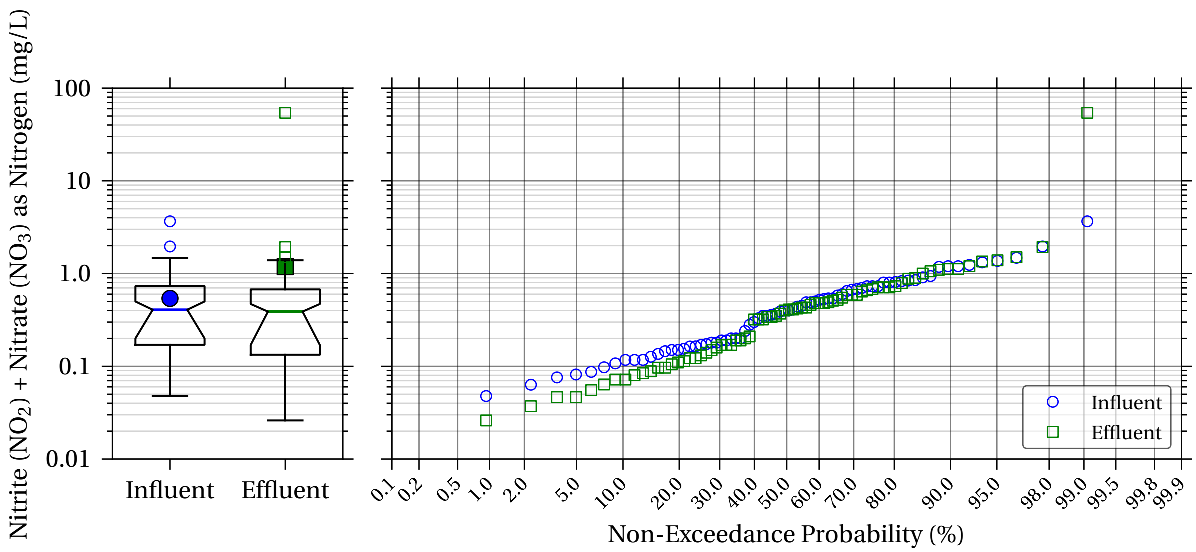


Figure 5.5: Box and Probability Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Manufactured Device BMPs

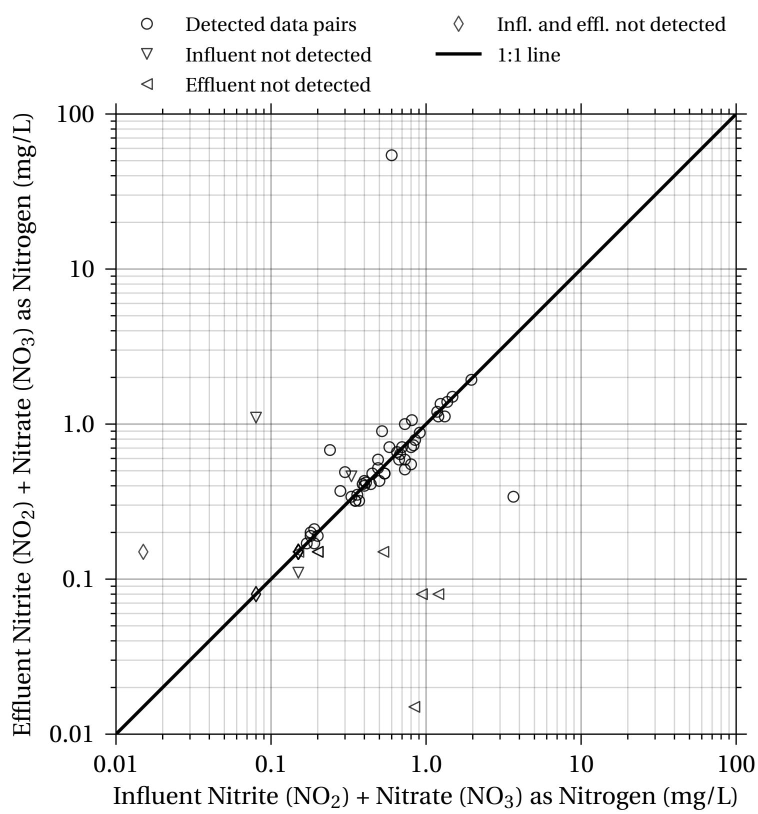


Figure 5.6: Influent vs. Effluent Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Manufactured Device BMPs

5.4 NO_3 or NO_3/NO_2

Table 5.4: Summary of NO_3 or NO_3/NO_2 at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	74	74
Number of Non-detects	18	22
Number of Studies	7	7
Min, Max (mg/L)	0.0478, 3.66	0.0261, 54.2
Mean (mg/L) (95% confidence interval)	0.54 (0.421, 0.665)	1.19 (0.376, 2.65)
Standard Deviation (mg/L)	0.523	4.99
Geometric Mean (mg/L) (95% confidence interval)	0.363 (0.294, 0.446)	0.325 (0.248, 0.424)
Geometric Standard Deviation (mg/L)	2.46	3.18
Coefficient of Variation	0.998	5.21
Skewness	2.99	8.37
Median (mg/L) (95% confidence interval)	0.405 (0.2, 0.5)	0.389 (0.18, 0.47)
25^{th}, 75^{th} percentiles (mg/L)	0.171, 0.73	0.133, 0.675
Number of data pairs	74	
Wilcoxon p-value	0.382	
Mann-Whitney p-value	0.401	

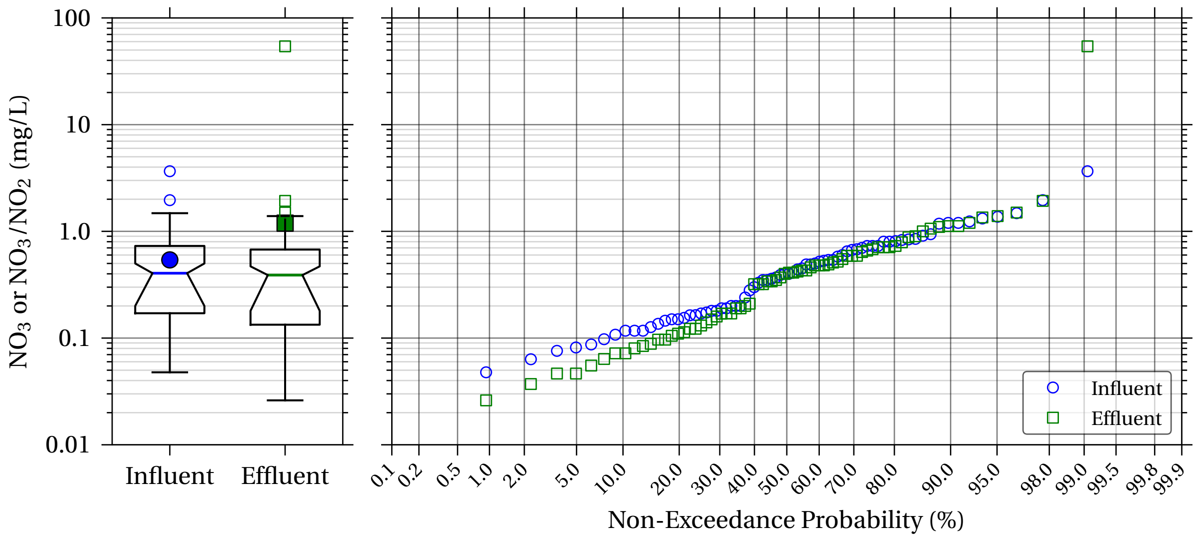


Figure 5.7: Box and Probability Plots of NO_3 or NO_3/NO_2 at Manufactured Device BMPs

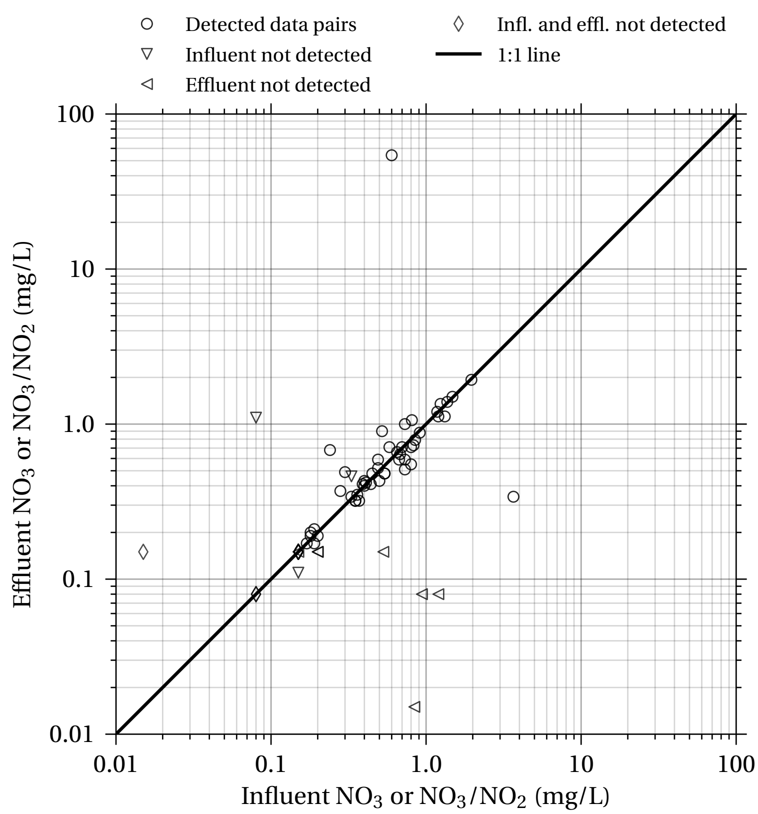


Figure 5.8: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Manufactured Device BMPs

5.5 Total Phosphorus

Table 5.5: Summary of Total Phosphorus at Manufactured Device BMPs

Statistic	Inlet	Outlet
Count	107	106
Number of Non-detects	5	5
Number of Studies	11	11
Min, Max (mg/L)	0.0227, 3.62	0.021, 1.26
Mean (mg/L) (95% confidence interval)	0.333 (0.252, 0.423)	0.223 (0.184, 0.264)
Standard Deviation (mg/L)	0.444	0.208
Geometric Mean (mg/L) (95% confidence interval)	0.207 (0.174, 0.246)	0.158 (0.135, 0.185)
Geometric Standard Deviation (mg/L)	2.48	2.28
Coefficient of Variation	1.39	0.945
Skewness	4.4	2.27
Median (mg/L) (95% confidence interval)	0.195 (0.15, 0.228)	0.157 (0.115, 0.185)
25^{th}, 75^{th} percentiles (mg/L)	0.115, 0.38	0.09, 0.258
Number of data pairs	106	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.036	

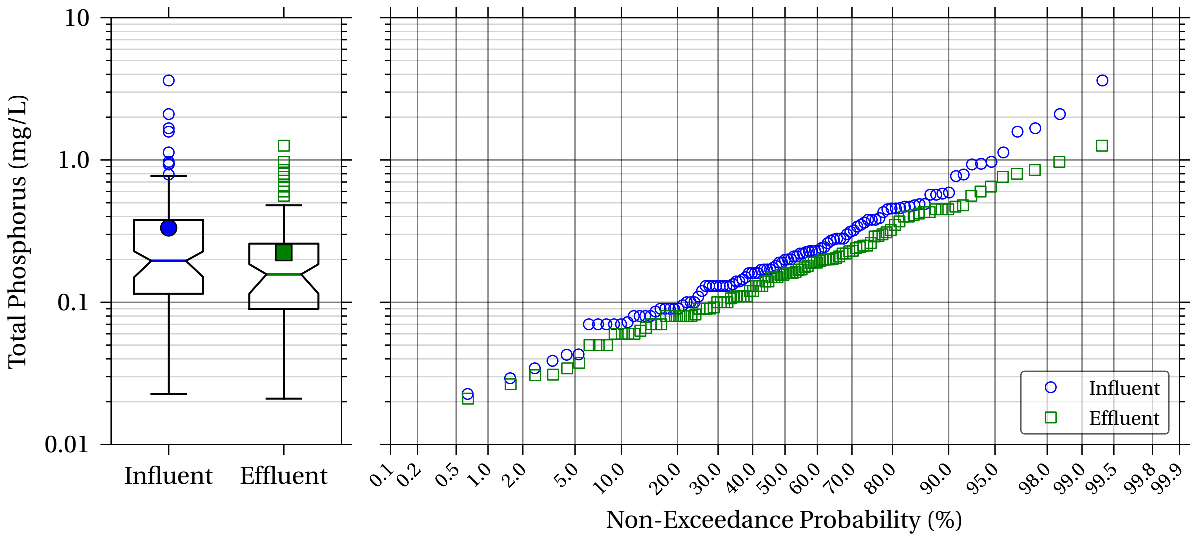


Figure 5.9: Box and Probability Plots of Total Phosphorus at Manufactured Device BMPs

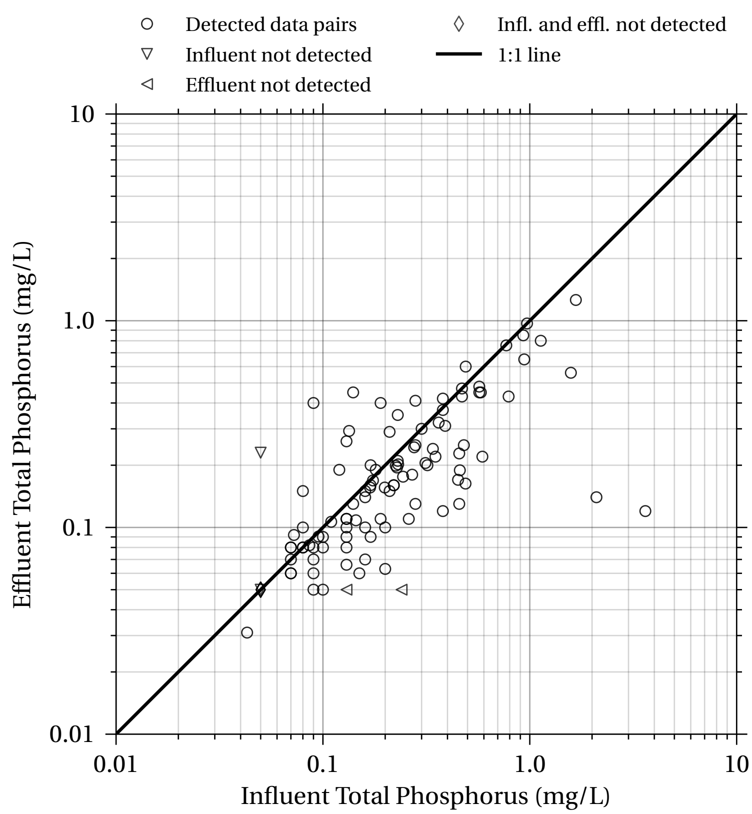


Figure 5.10: Influent vs. Effluent Plots of Total Phosphorus at Manufactured Device BMPs

5.6 Dissolved Phosphorus

Table 5.6: Summary of Dissolved Phosphorus at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	74	74
Number of Non-detects	8	10
Number of Studies	7	7
Min, Max (mg/L)	0.00796, 3.31	0.00777, 1.85
Mean (mg/L) (95% confidence interval)	0.343 (0.223, 0.472)	0.29 (0.202, 0.387)
Standard Deviation (mg/L)	0.54	0.4
Geometric Mean (mg/L) (95% confidence interval)	0.141 (0.104, 0.192)	0.131 (0.0986, 0.176)
Geometric Standard Deviation (mg/L)	3.72	3.55
Coefficient of Variation	1.61	1.41
Skewness	3.0	2.3
Median (mg/L) (95% confidence interval)	0.121 (0.08, 0.18)	0.125 (0.065, 0.185)
25^{th}, 75^{th} percentiles (mg/L)	0.05, 0.31	0.05, 0.36
Number of data pairs	74	
Wilcoxon p-value	0.830	
Mann-Whitney p-value	0.809	

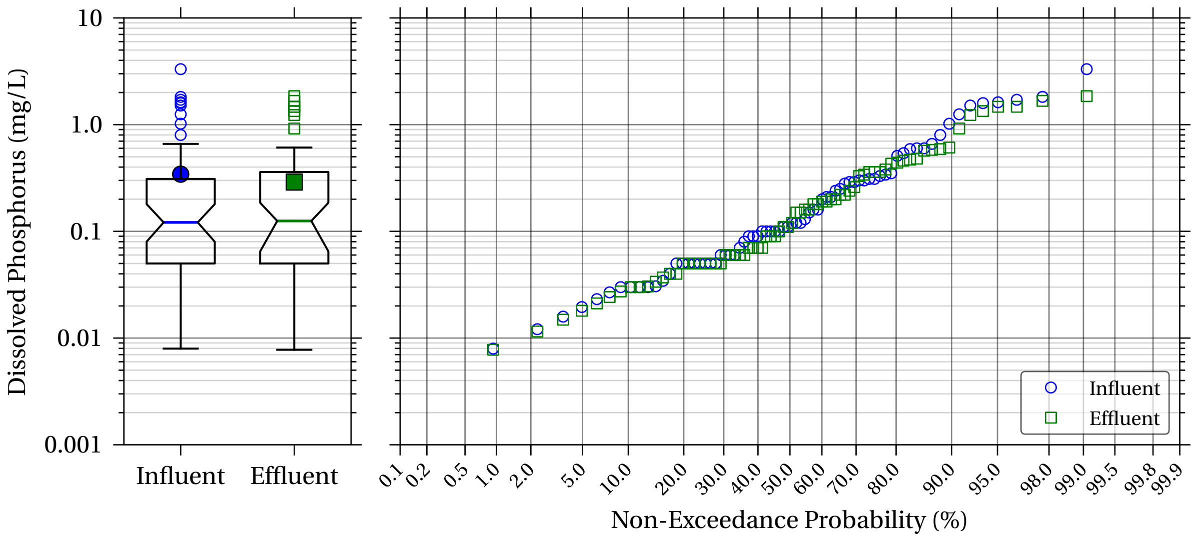


Figure 5.11: Box and Probability Plots of Dissolved Phosphorus at Manufactured Device BMPs

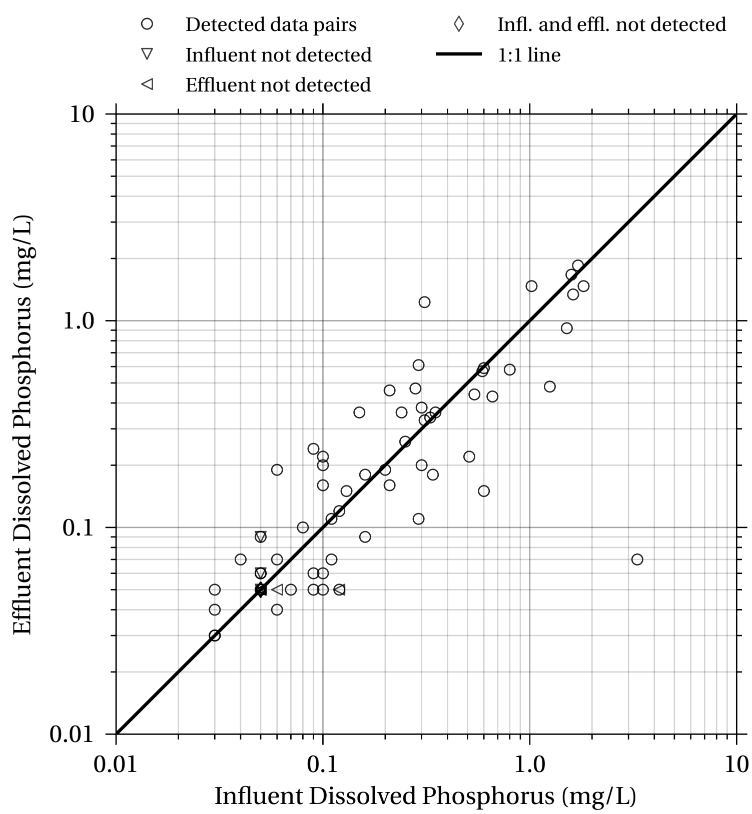


Figure 5.12: Influent vs. Effluent Plots of Dissolved Phosphorus at Manufactured Device BMPs

5.7 Orthophosphate

Table 5.7: Summary of Orthophosphate at Manufactured Device BMPs

Statistic	**Inlet**	**Outlet**
Count	69	69
Number of Non-detects	15	16
Number of Studies	7	7
Min, Max (mg/L)	0.00642, 0.96	0.0063, 0.63
Mean (mg/L) (95% confidence interval)	0.169 (0.123, 0.218)	0.12 (0.0902, 0.153)
Standard Deviation (mg/L)	0.2	0.131
Geometric Mean (mg/L) (95% confidence interval)	0.0883 (0.0667, 0.116)	0.0702 (0.0548, 0.0909)
Geometric Standard Deviation (mg/L)	3.23	2.9
Coefficient of Variation	1.21	1.1
Skewness	2.03	1.89
Median (mg/L) (95% confidence interval)	0.0926 (0.05, 0.12)	0.072 (0.05, 0.08)
25^{th}, 75^{th} percentiles (mg/L)	0.0358, 0.21	0.0312, 0.15
Number of data pairs	69	
Wilcoxon p-value	0.001	
Mann-Whitney p-value	0.256	

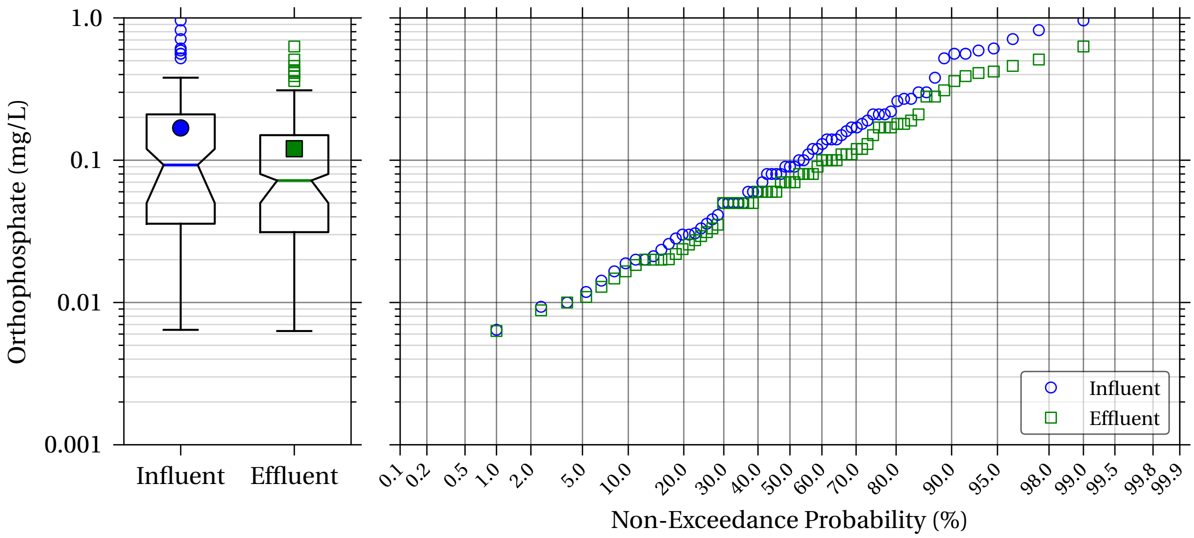


Figure 5.13: Box and Probability Plots of Orthophosphate at Manufactured Device BMPs

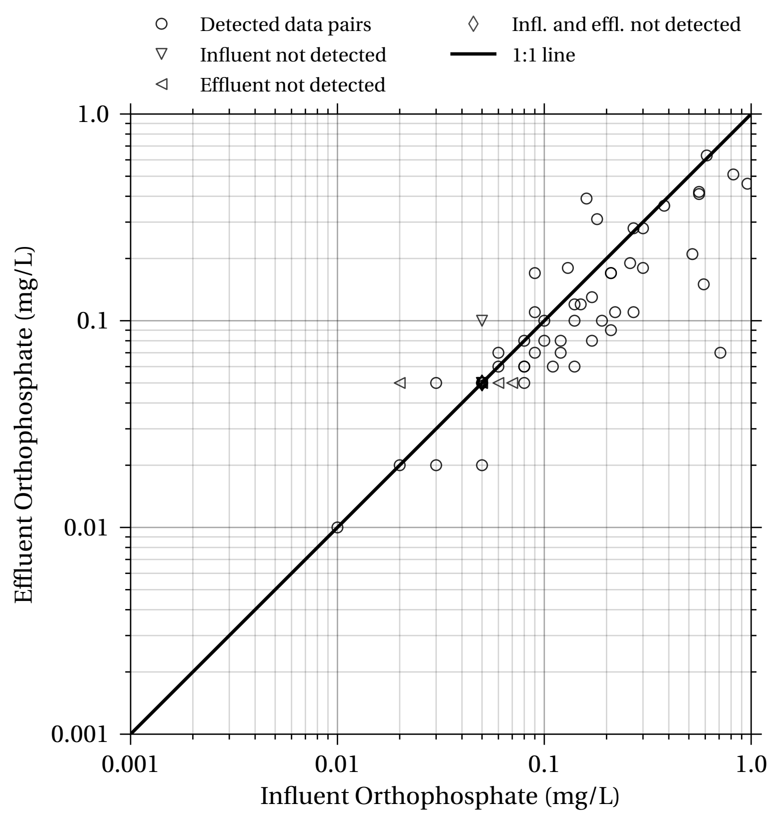


Figure 5.14: Influent vs. Effluent Plots of Orthophosphate at Manufactured Device BMPs

6 Media Filter

6.1 Total Kjeldahl Nitrogen

Table 6.1: Summary of Total Kjeldahl Nitrogen at Media Filter BMPs

Statistic	**Inlet**	**Outlet**
Count	57	56
Number of Non-detects	13	15
Number of Studies	4	4
Min, Max (mg/L)	0.0831, 28.0	0.187, 2.9
Mean (mg/L) (95% confidence interval)	2.85 (1.77, 4.03)	1.1 (0.913, 1.3)
Standard Deviation (mg/L)	4.29	0.725
Geometric Mean (mg/L) (95% confidence interval)	1.24 (0.891, 1.76)	0.875 (0.723, 1.05)
Geometric Standard Deviation (mg/L)	3.6	2.01
Coefficient of Variation	1.58	0.666
Skewness	3.54	0.893
Median (mg/L) (95% confidence interval)	1.16 (0.7, 2.0)	0.893 (0.65, 1.05)
25^{th}, 75^{th} percentiles (mg/L)	0.54, 3.0	0.564, 1.5
Number of data pairs	56	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.136	

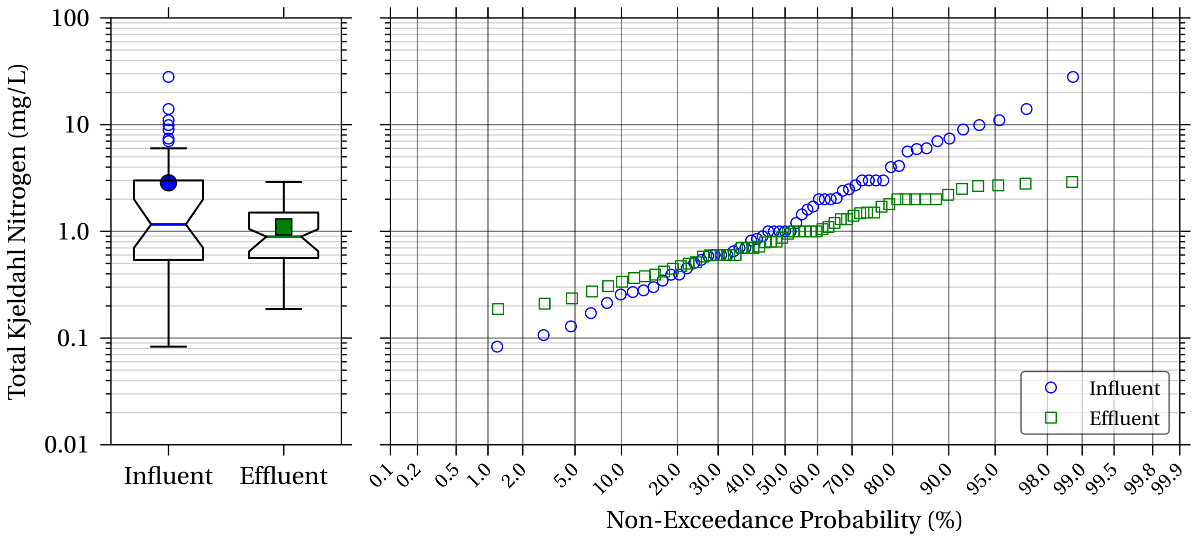


Figure 6.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Media Filter BMPs

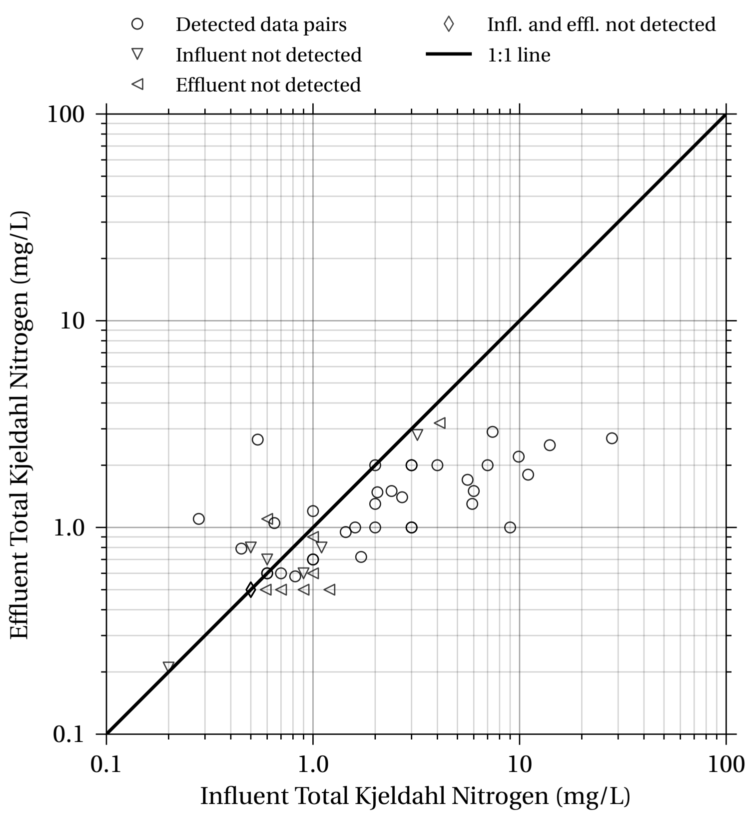


Figure 6.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Media Filter BMPs

6.2 NO_3 or NO_3/NO_2

Table 6.2: Summary of NO_3 or NO_3/NO_2 at Media Filter BMPs

Statistic	Inlet	Outlet
Count	57	56
Number of Non-detects	1	0
Number of Studies	4	4
Min, Max (mg/L)	0.06, 2.85	0.06, 7.21
Mean (mg/L) (95% confidence interval)	0.819 (0.65, 0.999)	1.17 (0.866, 1.49)
Standard Deviation (mg/L)	0.683	1.19
Geometric Mean (mg/L) (95% confidence interval)	0.578 (0.466, 0.731)	0.732 (0.566, 0.963)
Geometric Standard Deviation (mg/L)	2.35	2.71
Coefficient of Variation	0.847	1.05
Skewness	1.38	2.55
Median (mg/L) (95% confidence interval)	0.548 (0.4, 0.751)	0.79 (0.47, 1.02)
25^{th}, 75^{th} percentiles (mg/L)	0.34, 1.1	0.347, 1.63
Number of data pairs	56	
Wilcoxon p-value	0.013	
Mann-Whitney p-value	0.228	

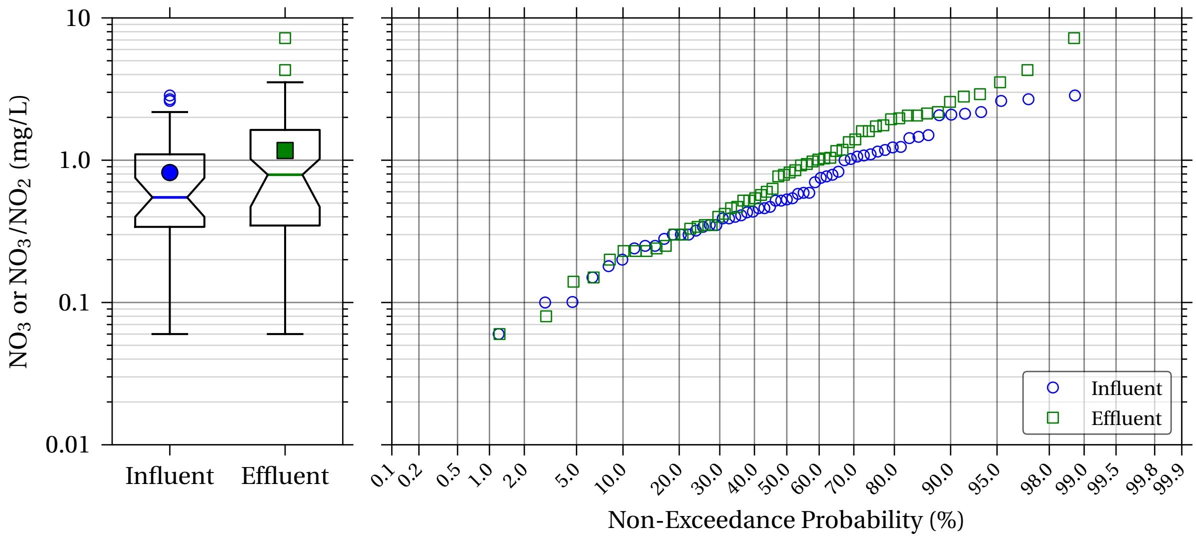


Figure 6.3: Box and Probability Plots of NO_3 or NO_3/NO_2 at Media Filter BMPs

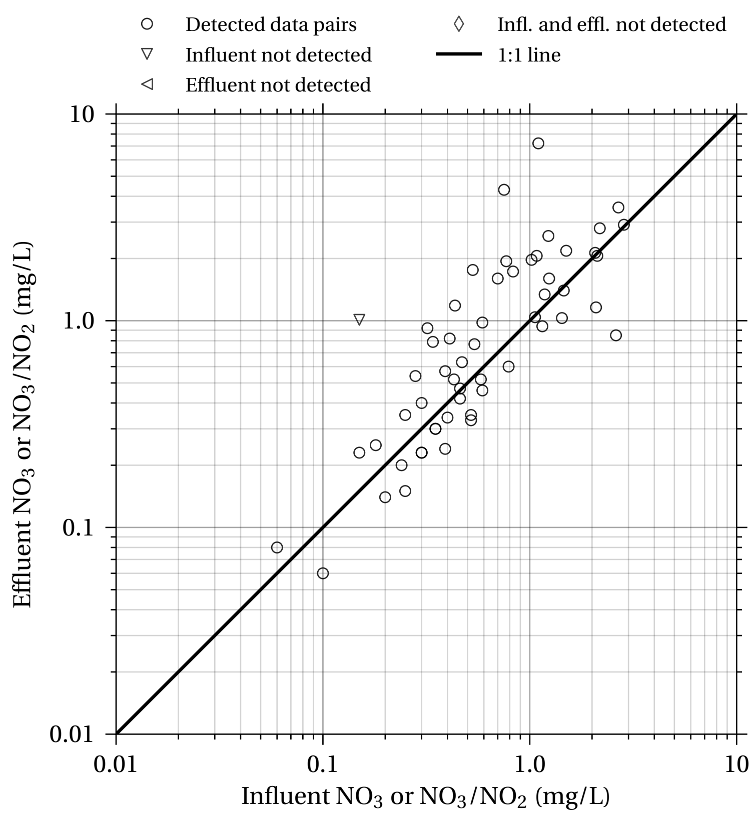


Figure 6.4: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Media Filter BMPs

6.3 Total Nitrogen

Table 6.3: Summary of Total Nitrogen at Media Filter BMPs

Statistic	Inlet	Outlet
Count	46	46
Number of Non-detects	0	0
Number of Studies	3	3
Min, Max (mg/L)	0.15, 30.1	0.08, 8.21
Mean (mg/L) (95% confidence interval)	4.19 (2.69, 5.75)	2.3 (1.76, 2.85)
Standard Deviation (mg/L)	5.14	1.83
Geometric Mean (mg/L) (95% confidence interval)	2.15 (1.52, 3.03)	1.48 (1.08, 2.03)
Geometric Standard Deviation (mg/L)	3.27	2.89
Coefficient of Variation	1.29	0.81
Skewness	2.8	1.08
Median (mg/L) (95% confidence interval)	2.28 (1.25, 3.39)	1.86 (1.15, 2.62)
25^{th}, 75^{th} percentiles (mg/L)	0.962, 4.41	0.935, 3.39
Number of data pairs	46	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.204	

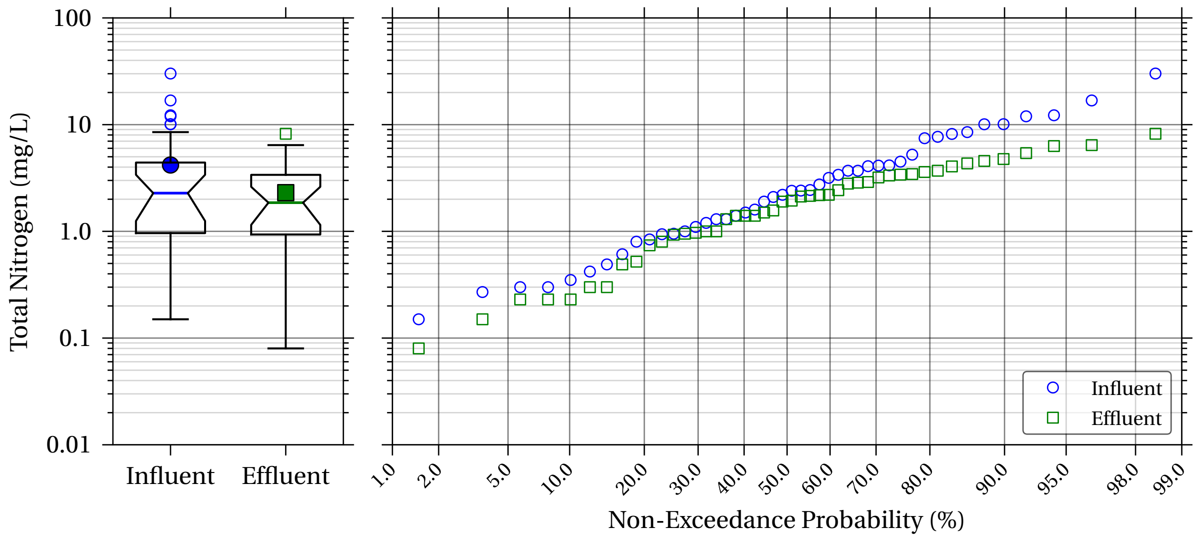


Figure 6.5: Box and Probability Plots of Total Nitrogen at Media Filter BMPs

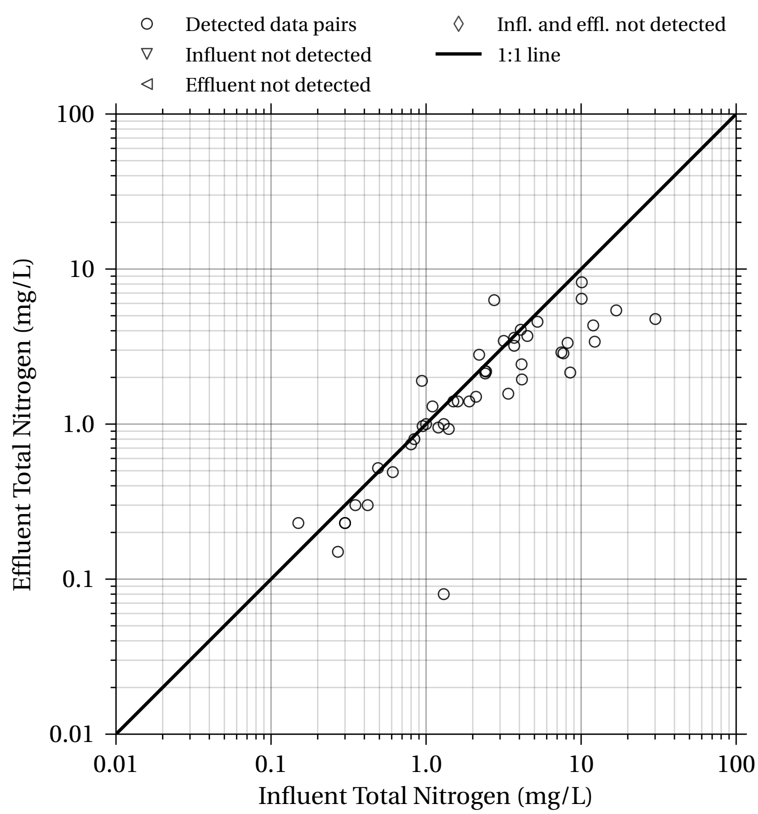


Figure 6.6: Influent vs. Effluent Plots of Total Nitrogen at Media Filter BMPs

6.4 Total Phosphorus

Table 6.4: Summary of Total Phosphorus at Media Filter BMPs

Statistic	Inlet	Outlet
Count	57	62
Number of Non-detects	3	3
Number of Studies	4	5
Min, Max (mg/L)	0.0244, 1.4	0.03, 0.52
Mean (mg/L) (95% confidence interval)	0.261 (0.195, 0.328)	0.129 (0.108, 0.153)
Standard Deviation (mg/L)	0.252	0.0875
Geometric Mean (mg/L) (95% confidence interval)	0.175 (0.14, 0.222)	0.109 (0.0943, 0.125)
Geometric Standard Deviation (mg/L)	2.42	1.76
Coefficient of Variation	0.995	0.695
Skewness	2.22	2.44
Median (mg/L) (95% confidence interval)	0.155 (0.11, 0.18)	0.109 (0.09, 0.11)
25^{th}, 75^{th} percentiles (mg/L)	0.1, 0.35	0.0825, 0.148
Number of data pairs	56	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.002	

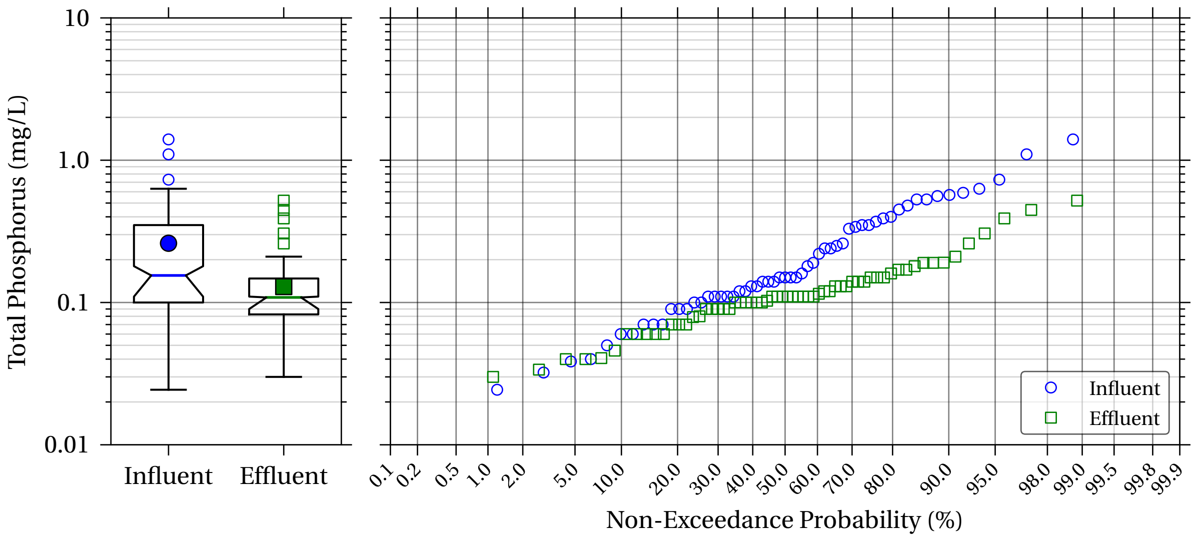


Figure 6.7: Box and Probability Plots of Total Phosphorus at Media Filter BMPs

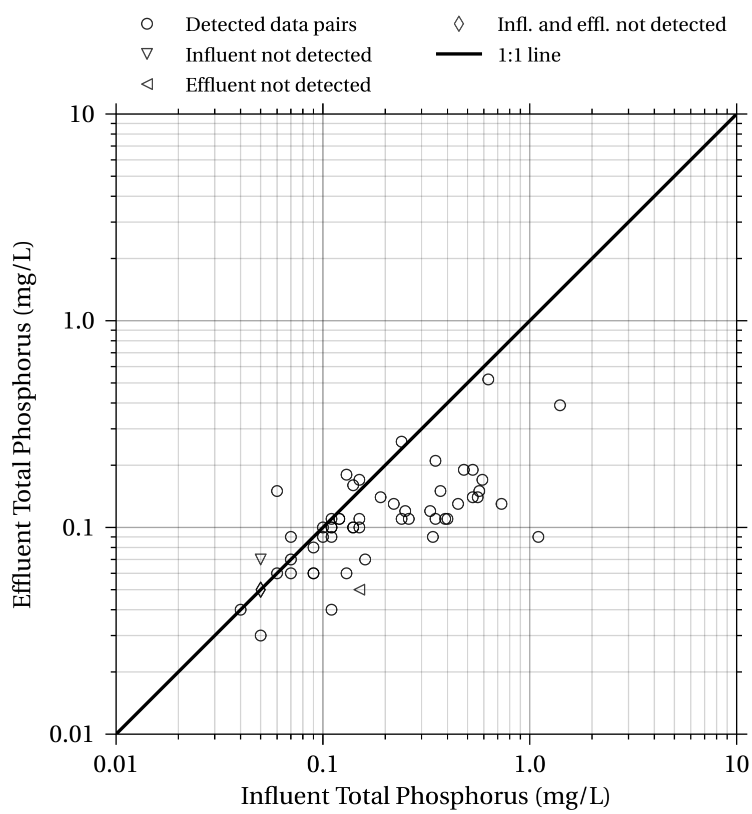


Figure 6.8: Influent vs. Effluent Plots of Total Phosphorus at Media Filter BMPs

6.5 Orthophosphate

Table 6.5: Summary of Orthophosphate at Media Filter BMPs

Statistic	Inlet	Outlet
Count	57	56
Number of Non-detects	2	5
Number of Studies	4	4
Min, Max (mg/L)	0.02, 1.4	0.01, 0.14
Mean (mg/L) (95% confidence interval)	0.159 (0.11, 0.215)	0.0609 (0.0526, 0.069)
Standard Deviation (mg/L)	0.197	0.0304
Geometric Mean (mg/L) (95% confidence interval)	0.1 (0.0793, 0.127)	0.0519 (0.044, 0.0607)
Geometric Standard Deviation (mg/L)	2.45	1.83
Coefficient of Variation	1.32	0.506
Skewness	3.92	0.262
Median (mg/L) (95% confidence interval)	0.0908 (0.07, 0.11)	0.0608 (0.04, 0.07)
25^{th}, 75^{th} percentiles (mg/L)	0.05, 0.18	0.03, 0.09
Number of data pairs	56	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

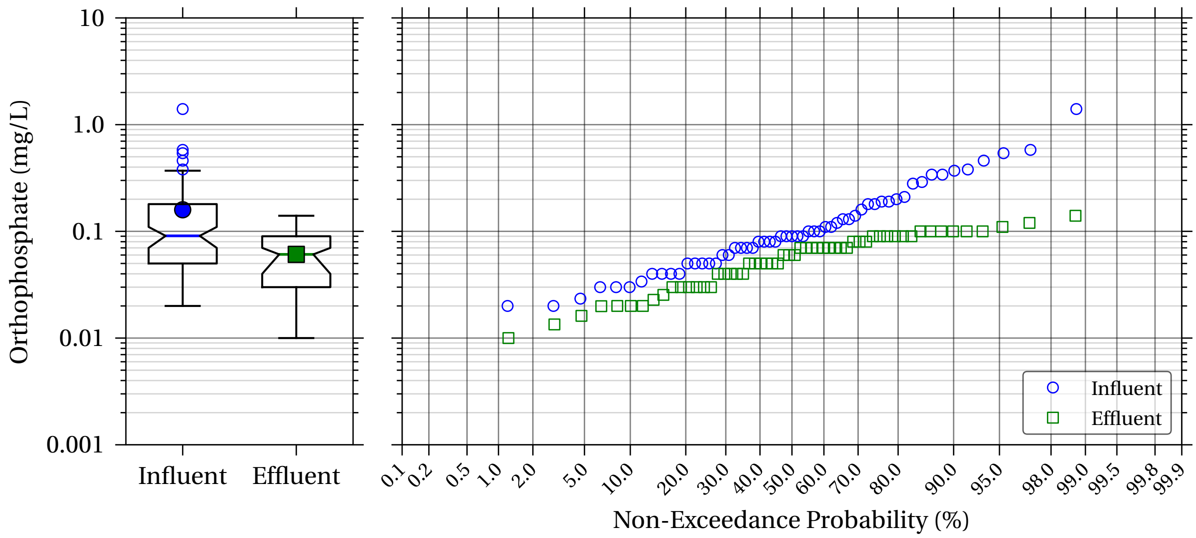


Figure 6.9: Box and Probability Plots of Orthophosphate at Media Filter BMPs

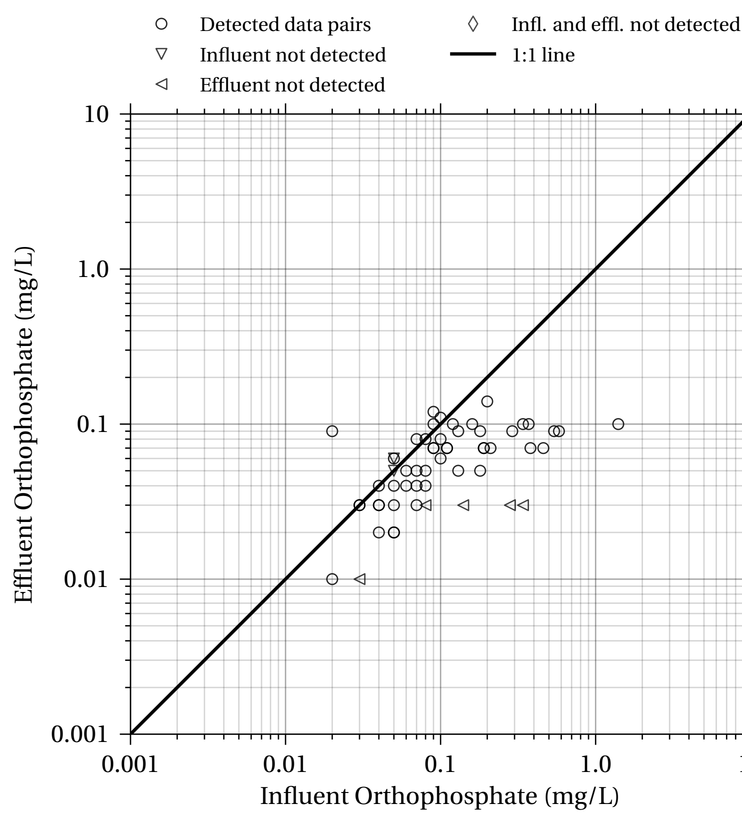


Figure 6.10: Influent vs. Effluent Plots of Orthophosphate at Media Filter BMPs

7 Porous Pavement

7.1 Total Kjeldahl Nitrogen

Table 7.1: Summary of Total Kjeldahl Nitrogen at Porous Pavement BMPs

Statistic	**Inlet**	**Outlet**
Count	50	163
Number of Non-detects	0	6
Number of Studies	5	11
Min, Max (mg/L)	0.192, 4.06	0.05, 4.86
Mean (mg/L) (95% confidence interval)	0.821 (0.639, 1.01)	0.87 (0.754, 0.998)
Standard Deviation (mg/L)	0.644	0.795
Geometric Mean (mg/L) (95% confidence interval)	0.637 (0.523, 0.773)	0.605 (0.527, 0.692)
Geometric Standard Deviation (mg/L)	2.0	2.41
Coefficient of Variation	0.816	0.921
Skewness	2.5	2.09
Median (mg/L) (95% confidence interval)	0.626 (0.388, 0.912)	0.607 (0.47, 0.67)
25^{th}, 75^{th} percentiles (mg/L)	0.388, 0.999	0.325, 1.1
Number of data pairs	47	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.857	

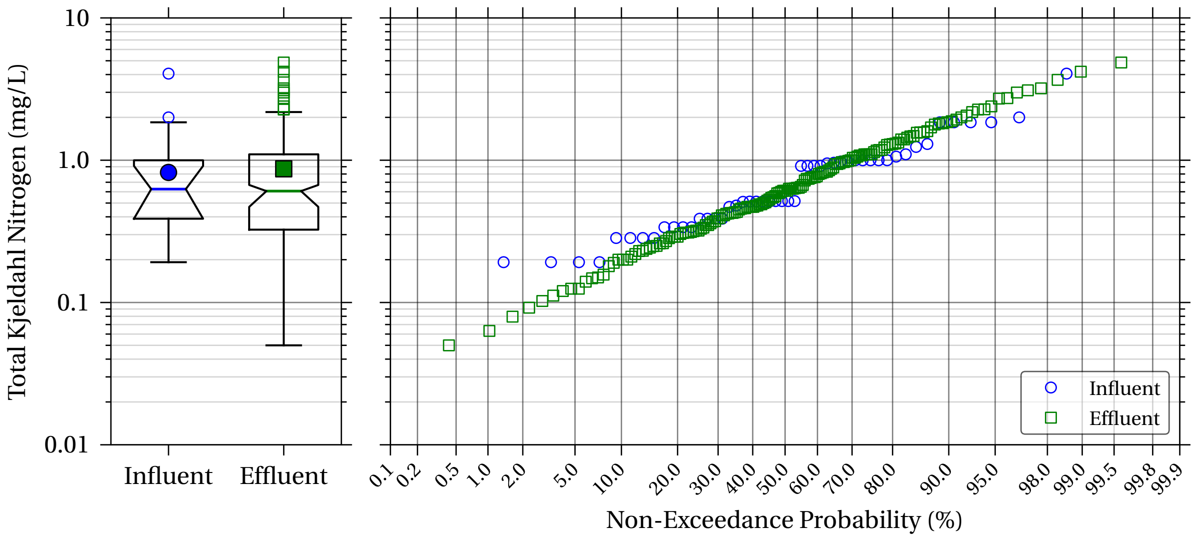


Figure 7.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Porous Pavement BMPs

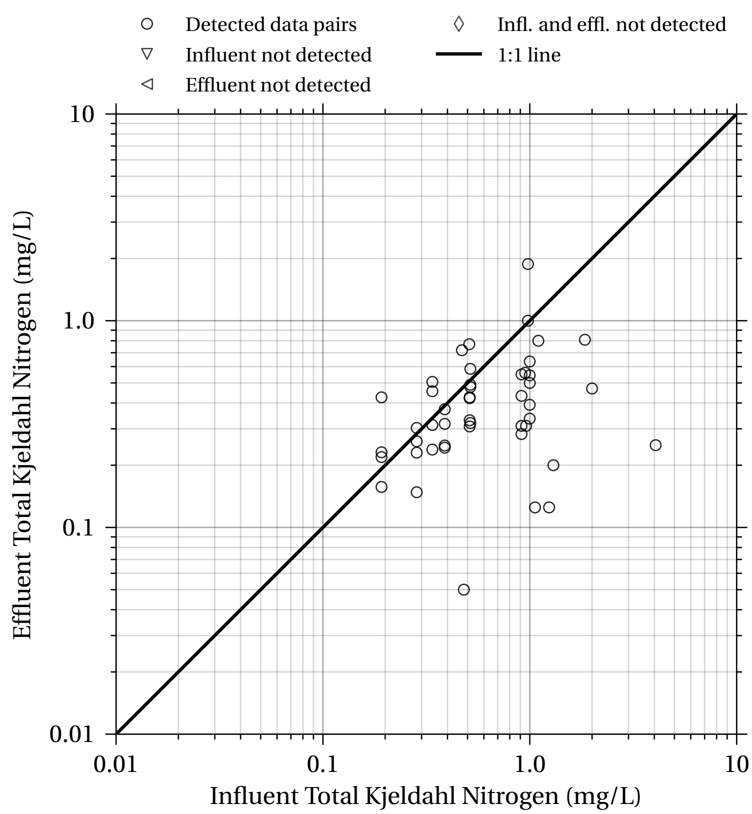


Figure 7.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Porous Pavement BMPs

7.2 Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen

Table 7.2: Summary of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Porous Pavement BMPs

Statistic	**Inlet**	**Outlet**
Count	42	128
Number of Non-detects	2	1
Number of Studies	5	9
Min, Max (mg/L)	0.02, 0.8	0.05, 3.77
Mean (mg/L) (95% confidence interval)	0.261 (0.211, 0.316)	0.649 (0.566, 0.736)
Standard Deviation (mg/L)	0.168	0.487
Geometric Mean (mg/L) (95% confidence interval)	0.208 (0.166, 0.261)	0.524 (0.468, 0.587)
Geometric Standard Deviation (mg/L)	2.07	1.93
Coefficient of Variation	0.662	0.764
Skewness	1.51	3.02
Median (mg/L) (95% confidence interval)	0.227 (0.156, 0.275)	0.525 (0.46, 0.58)
25^{th}, 75^{th} percentiles (mg/L)	0.156, 0.344	0.36, 0.78
Number of data pairs	42	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

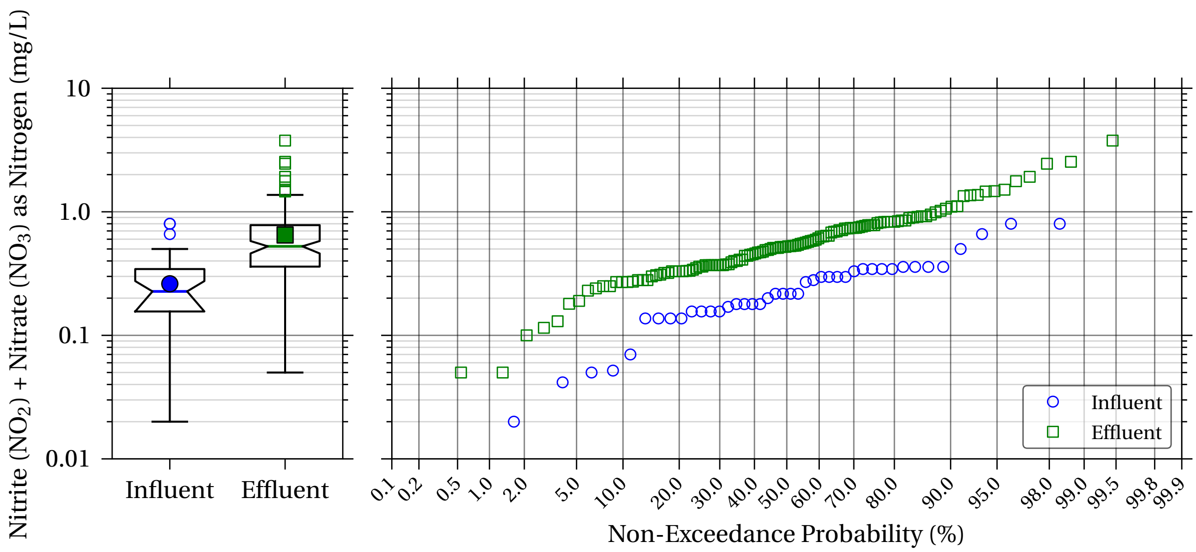


Figure 7.3: Box and Probability Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Porous Pavement BMPs

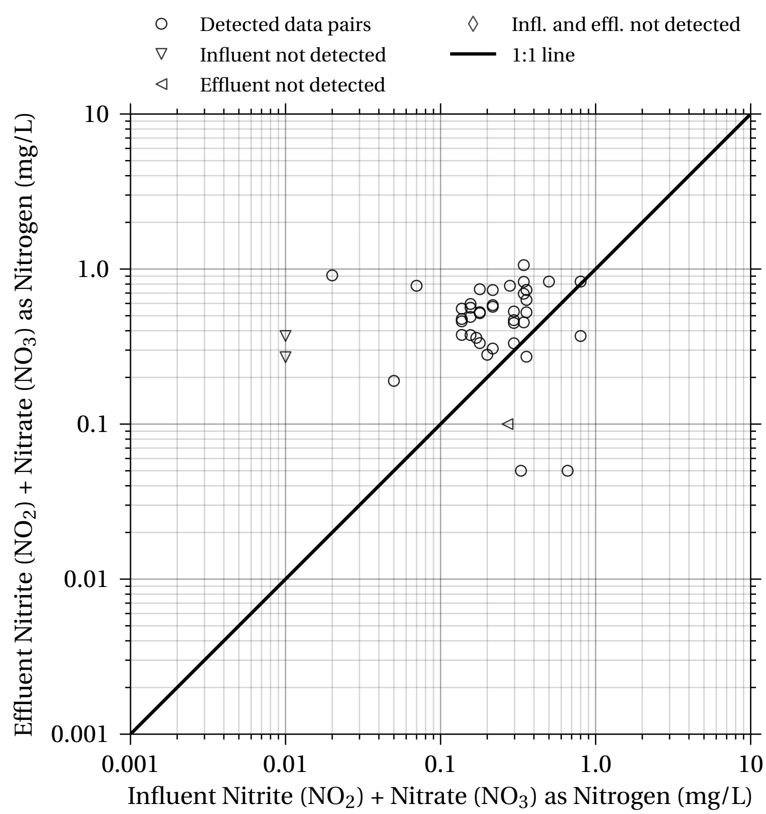


Figure 7.4: Influent vs. Effluent Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Porous Pavement BMPs

7.3 NO_3 or NO_3/NO_2

Table 7.3: Summary of NO_3 or NO_3/NO_2 at Porous Pavement BMPs

Statistic	Inlet	Outlet
Count	42	158
Number of Non-detects	2	10
Number of Studies	5	11
Min, Max (mg/L)	0.02, 0.8	0.05, 7.6
Mean (mg/L) (95% confidence interval)	0.261 (0.212, 0.316)	0.703 (0.583, 0.83)
Standard Deviation (mg/L)	0.168	0.785
Geometric Mean (mg/L) (95% confidence interval)	0.208 (0.167, 0.259)	0.488 (0.428, 0.557)
Geometric Standard Deviation (mg/L)	2.07	2.31
Coefficient of Variation	0.662	1.15
Skewness	1.51	4.86
Median (mg/L) (95% confidence interval)	0.226 (0.156, 0.275)	0.501 (0.4, 0.545)
25^{th}, 75^{th} percentiles (mg/L)	0.156, 0.344	0.32, 0.817
Number of data pairs	42	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

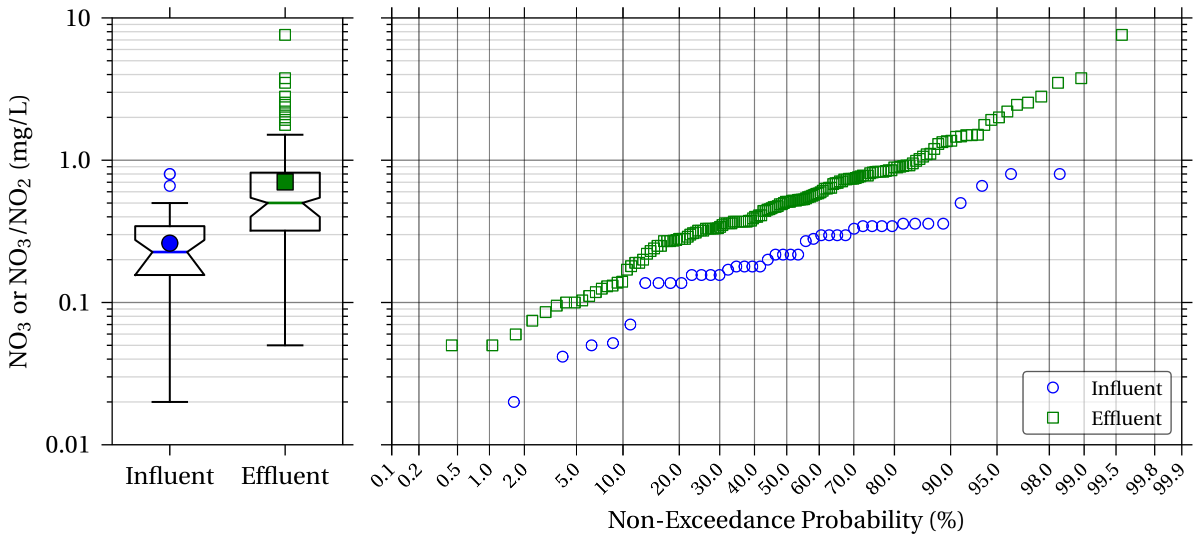


Figure 7.5: Box and Probability Plots of NO_3 or NO_3/NO_2 at Porous Pavement BMPs

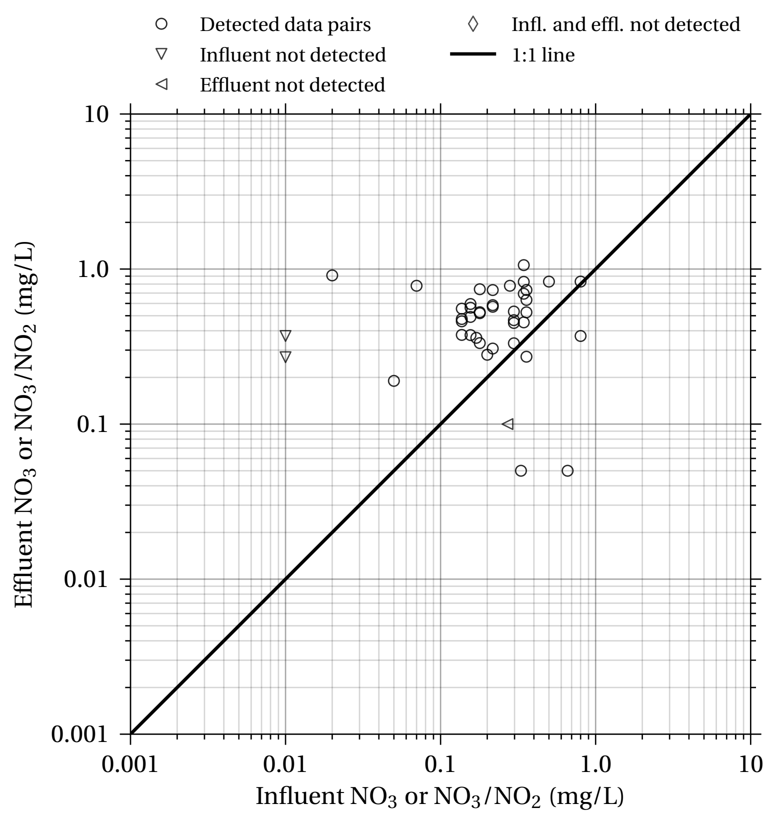


Figure 7.6: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Porous Pavement BMPs

7.4 Total Nitrogen

Table 7.4: Summary of Total Nitrogen at Porous Pavement BMPs

Statistic	Inlet	Outlet
Count	NA	130
Number of Non-detects	NA	0
Number of Studies	NA	7
Min, Max (mg/L)	NA	0.1, 9.0
Mean (mg/L) (95% confidence interval)	NA (NA)	1.73 (1.5, 1.96)
Standard Deviation (mg/L)	NA	1.35
Geometric Mean (mg/L) (95% confidence interval)	NA (NA)	1.24 (1.05, 1.44)
Geometric Standard Deviation (mg/L)	NA	2.47
Coefficient of Variation	NA	0.791
Skewness	NA	1.82
Median (mg/L) (95% confidence interval)	NA (NA)	1.45 (1.23, 1.6)
25^{th}, 75^{th} percentiles (mg/L)	NA	0.715, 2.25
Number of data pairs		14
Wilcoxon p-value		NA
Mann-Whitney p-value		NA

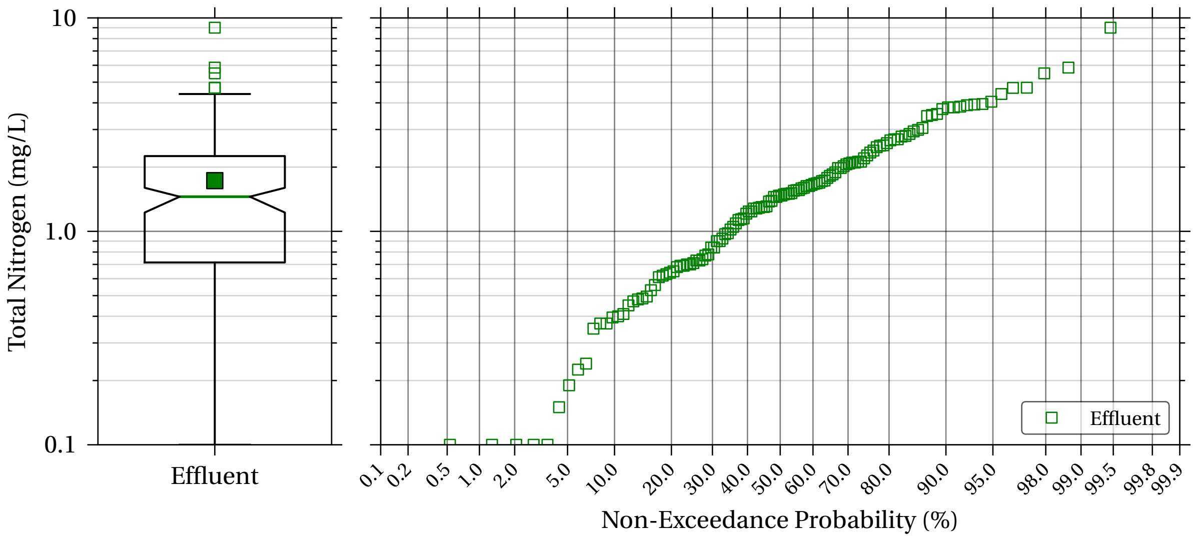


Figure 7.7: Box and Probability Plots of Total Nitrogen at Porous Pavement BMPs

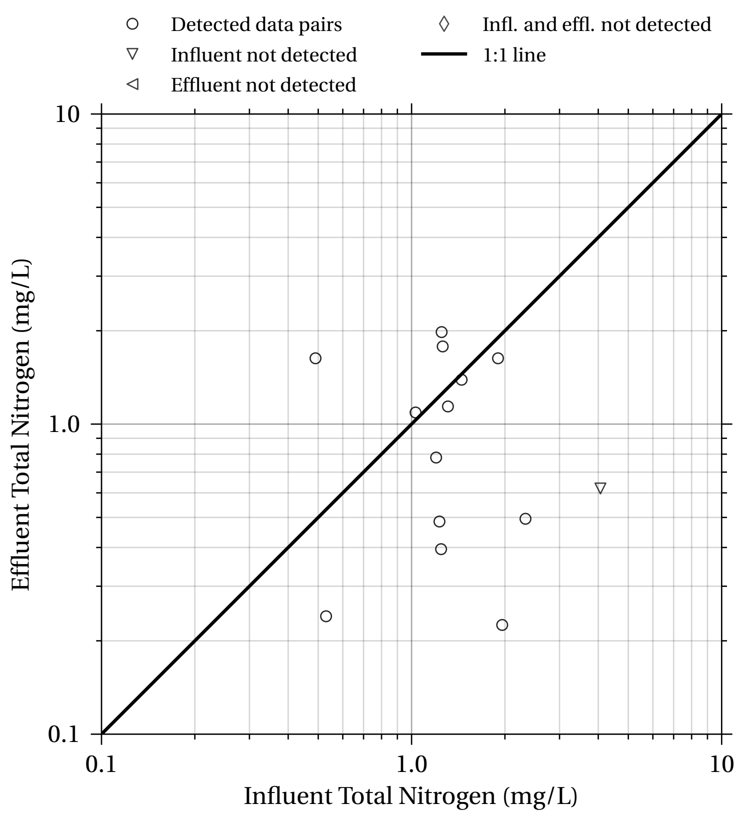


Figure 7.8: Influent vs. Effluent Plots of Total Nitrogen at Porous Pavement BMPs

7.5 Total Phosphorus

Table 7.5: Summary of Total Phosphorus at Porous Pavement BMPs

Statistic	**Inlet**	**Outlet**
Count	50	163
Number of Non-detects	0	3
Number of Studies	5	11
Min, Max (mg/L)	0.025, 0.98	0.00961, 2.6
Mean (mg/L) (95% confidence interval)	0.127 (0.0909, 0.165)	0.135 (0.107, 0.171)
Standard Deviation (mg/L)	0.128	0.206
Geometric Mean (mg/L) (95% confidence interval)	0.0928 (0.0757, 0.114)	0.09 (0.079, 0.102)
Geometric Standard Deviation (mg/L)	2.08	2.33
Coefficient of Variation	1.1	1.64
Skewness	4.56	8.72
Median (mg/L) (95% confidence interval)	0.0947 (0.061, 0.12)	0.089 (0.073, 0.09)
25^{th}, 75^{th} percentiles (mg/L)	0.061, 0.152	0.06, 0.145
Number of data pairs	47	
Wilcoxon p-value	0.710	
Mann-Whitney p-value	0.835	

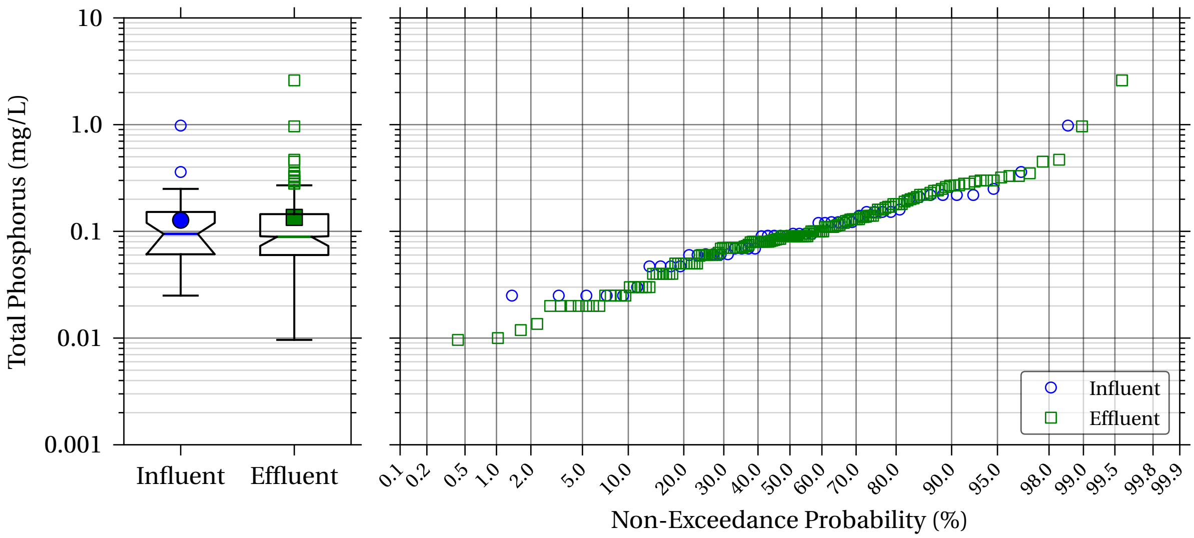


Figure 7.9: Box and Probability Plots of Total Phosphorus at Porous Pavement BMPs

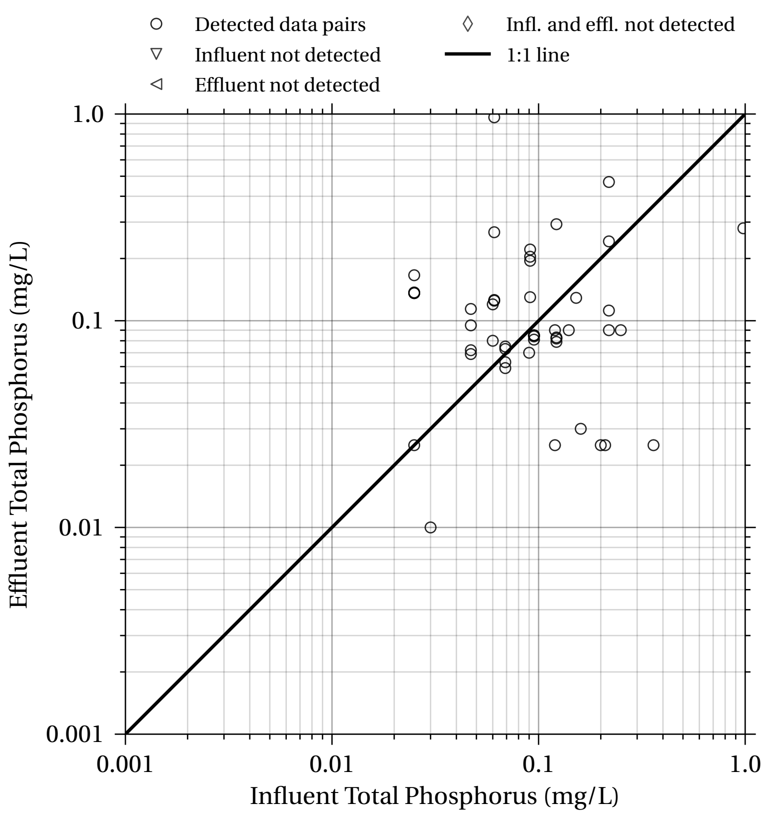


Figure 7.10: Influent vs. Effluent Plots of Total Phosphorus at Porous Pavement BMPs

7.6 Orthophosphate

Table 7.6: Summary of Orthophosphate at Porous Pavement BMPs

Statistic	Inlet	Outlet
Count	42	69
Number of Non-detects	0	9
Number of Studies	5	7
Min, Max (mg/L)	0.005, 0.186	0.00318, 2.4
Mean (mg/L) (95% confidence interval)	0.0577 (0.041, 0.0738)	0.108 (0.0577, 0.177)
Standard Deviation (mg/L)	0.0536	0.252
Geometric Mean (mg/L) (95% confidence interval)	0.0336 (0.0237, 0.0474)	0.0457 (0.0345, 0.0602)
Geometric Standard Deviation (mg/L)	3.1	3.18
Coefficient of Variation	0.95	2.69
Skewness	1.26	7.16
Median (mg/L) (95% confidence interval)	0.0421 (0.02, 0.059)	0.0398 (0.028, 0.045)
25^{th}, 75^{th} percentiles (mg/L)	0.017, 0.062	0.028, 0.08
Number of data pairs	39	
Wilcoxon p-value	0.857	
Mann-Whitney p-value	0.398	

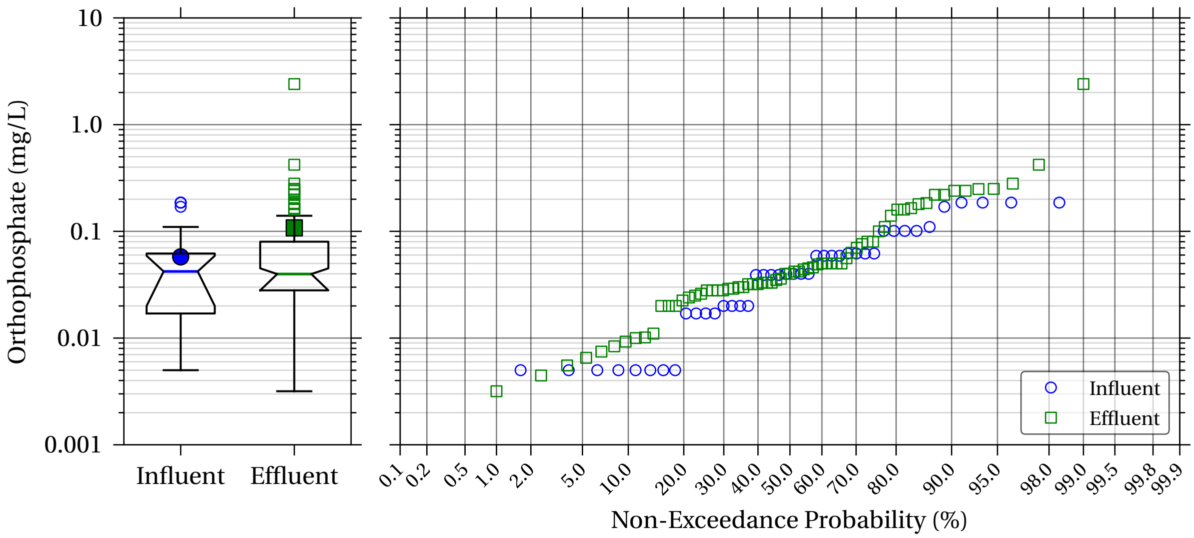


Figure 7.11: Box and Probability Plots of Orthophosphate at Porous Pavement BMPs

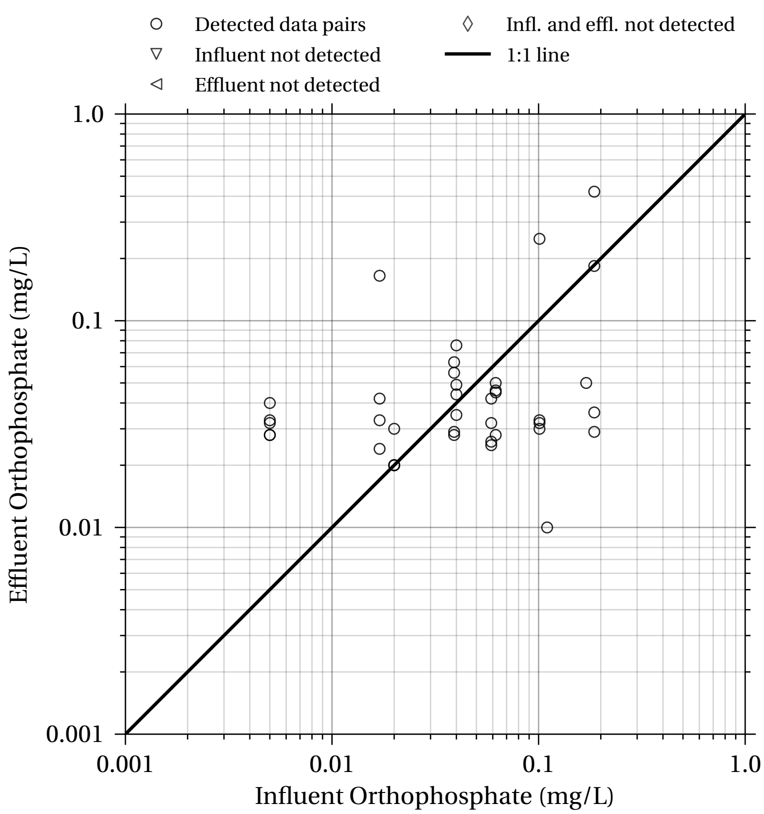


Figure 7.12: Influent vs. Effluent Plots of Orthophosphate at Porous Pavement BMPs

8 Retention Pond

8.1 Total Kjeldahl Nitrogen

Table 8.1: Summary of Total Kjeldahl Nitrogen at Retention Pond BMPs

Statistic	**Inlet**	**Outlet**
Count	21	32
Number of Non-detects	0	6
Number of Studies	3	4
Min, Max (mg/L)	0.53, 1.9	0.255, 1.4
Mean (mg/L) (95% confidence interval)	0.95 (0.826, 1.09)	0.696 (0.59, 0.804)
Standard Deviation (mg/L)	0.298	0.301
Geometric Mean (mg/L) (95% confidence interval)	0.909 (0.803, 1.03)	0.631 (0.539, 0.736)
Geometric Standard Deviation (mg/L)	1.32	1.55
Coefficient of Variation	0.33	0.442
Skewness	1.57	0.689
Median (mg/L) (95% confidence interval)	0.864 (0.86, 0.93)	0.657 (0.483, 0.8)
25^{th}, 75^{th} percentiles (mg/L)	0.85, 0.96	0.453, 0.873
Number of data pairs	21	
Wilcoxon p-value	0.001	
Mann-Whitney p-value	0.004	

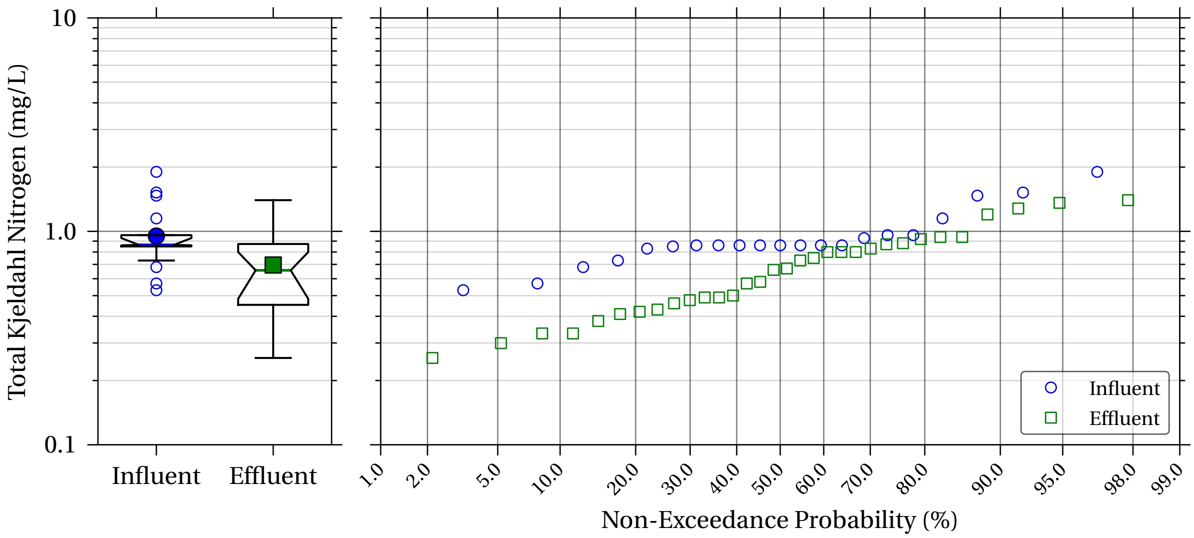


Figure 8.1: Box and Probability Plots of Total Kjeldahl Nitrogen at Retention Pond BMPs

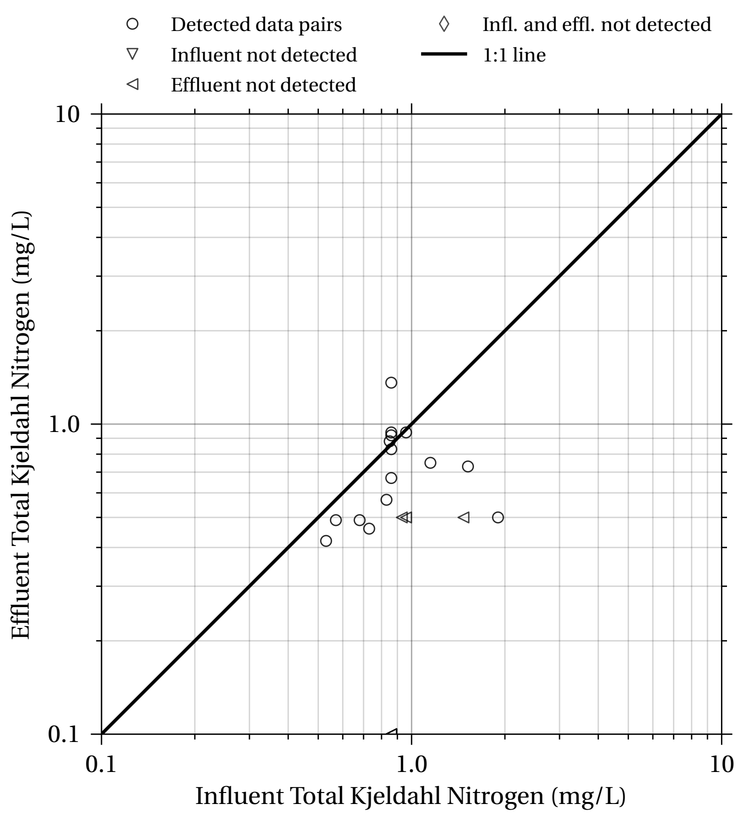


Figure 8.2: Influent vs. Effluent Plots of Total Kjeldahl Nitrogen at Retention Pond BMPs

8.2 Total Phosphorus

Table 8.2: Summary of Total Phosphorus at Retention Pond BMPs

Statistic	**Inlet**	**Outlet**
Count	21	32
Number of Non-detects	0	6
Number of Studies	3	4
Min, Max (mg/L)	0.05, 0.49	0.00769, 0.29
Mean (mg/L) (95% confidence interval)	0.165 (0.127, 0.207)	0.0913 (0.0673, 0.117)
Standard Deviation (mg/L)	0.0908	0.0704
Geometric Mean (mg/L) (95% confidence interval)	0.145 (0.117, 0.18)	0.0592 (0.0415, 0.0853)
Geometric Standard Deviation (mg/L)	1.62	2.8
Coefficient of Variation	0.584	0.79
Skewness	1.94	0.753
Median (mg/L) (95% confidence interval)	0.14 (0.14, 0.14)	0.0783 (0.0301, 0.12)
25^{th}, 75^{th} percentiles (mg/L)	0.12, 0.15	0.0269, 0.143
Number of data pairs	21	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.004	

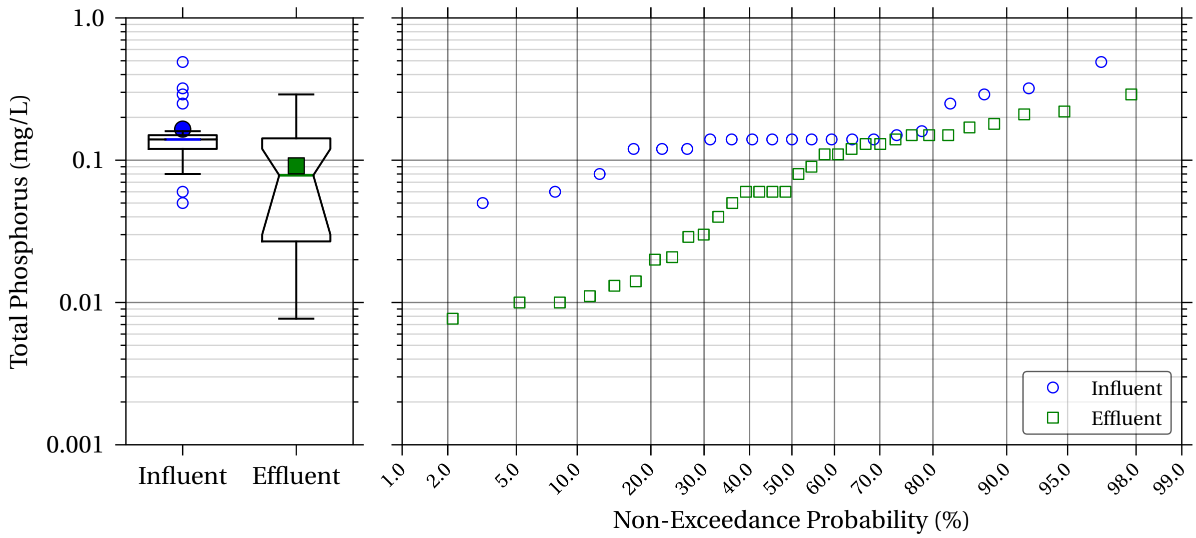


Figure 8.3: Box and Probability Plots of Total Phosphorus at Retention Pond BMPs

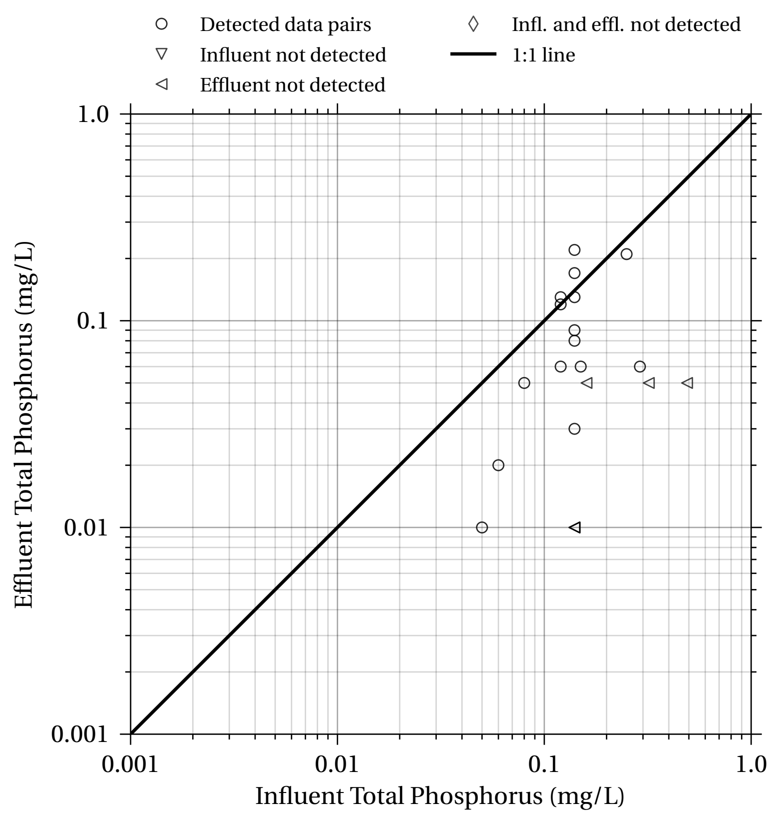


Figure 8.4: Influent vs. Effluent Plots of Total Phosphorus at Retention Pond BMPs

9 Wetland Basin

9.1 Ammonia as Nitrogen

Table 9.1: Summary of Ammonia as Nitrogen at Wetland Basin BMPs

Statistic	**Inlet**	**Outlet**
Count	111	110
Number of Non-detects	0	0
Number of Studies	4	4
Min, Max (mg/L)	0.00999, 2.99	0.002, 3.6
Mean (mg/L) (95% confidence interval)	0.221 (0.162, 0.288)	0.168 (0.11, 0.237)
Standard Deviation (mg/L)	0.334	0.334
Geometric Mean (mg/L) (95% confidence interval)	0.135 (0.114, 0.16)	0.0734 (0.0576, 0.0932)
Geometric Standard Deviation (mg/L)	2.51	3.64
Coefficient of Variation	1.6	2.18
Skewness	5.62	7.62
Median (mg/L) (95% confidence interval)	0.131 (0.0946, 0.16)	0.0778 (0.0569, 0.0942)
25^{th}, 75^{th} percentiles (mg/L)	0.076, 0.238	0.0371, 0.183
Number of data pairs	90	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	<0.001	

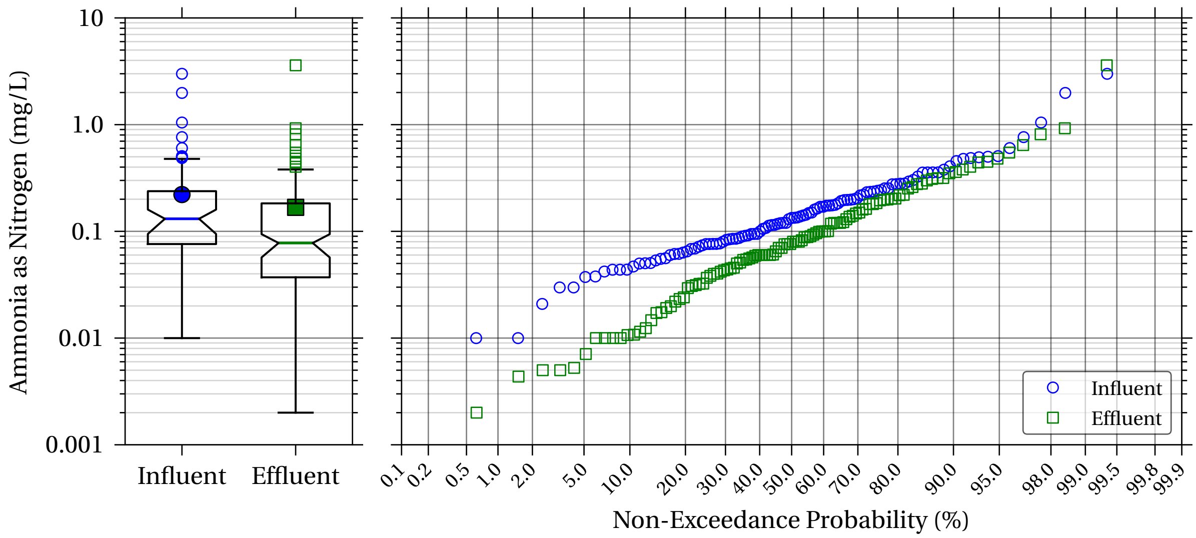


Figure 9.1: Box and Probability Plots of Ammonia as Nitrogen at Wetland Basin BMPs

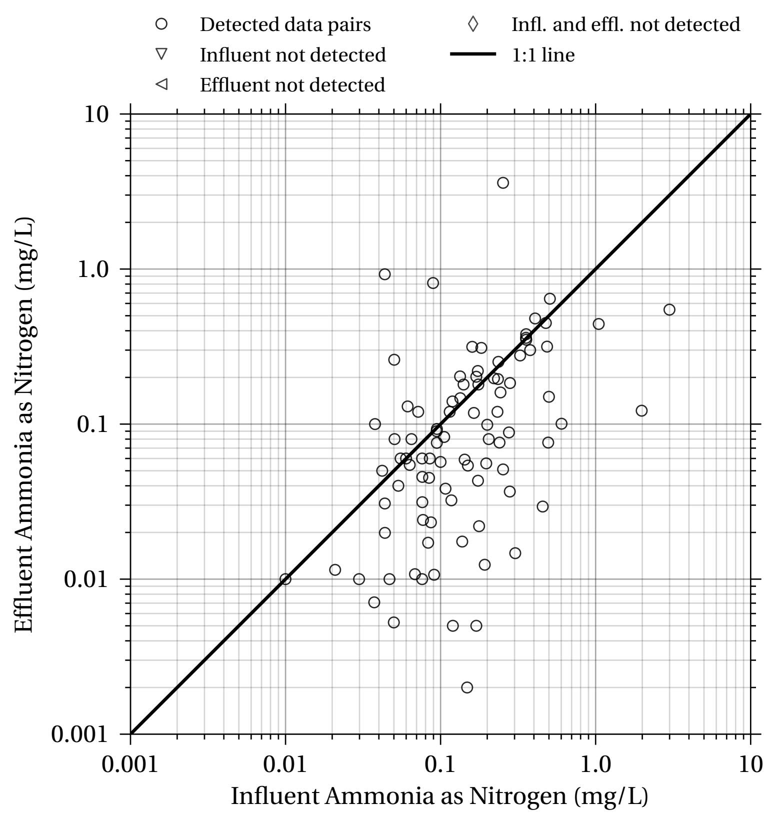


Figure 9.2: Influent vs. Effluent Plots of Ammonia as Nitrogen at Wetland Basin BMPs

9.2 Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen

Table 9.2: Summary of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Wetland Basin BMPs

Statistic	**Inlet**	**Outlet**
Count	72	79
Number of Non-detects	0	0
Number of Studies	3	3
Min, Max (mg/L)	0.0616, 5.22	0.000723, 8.06
Mean (mg/L) (95% confidence interval)	0.683 (0.536, 0.85)	0.552 (0.362, 0.778)
Standard Deviation (mg/L)	0.664	0.929
Geometric Mean (mg/L) (95% confidence interval)	0.478 (0.392, 0.582)	0.239 (0.171, 0.328)
Geometric Standard Deviation (mg/L)	2.34	4.32
Coefficient of Variation	1.02	1.81
Skewness	3.93	5.66
Median (mg/L) (95% confidence interval)	0.504 (0.333, 0.623)	0.249 (0.166, 0.366)
25^{th}, 75^{th} percentiles (mg/L)	0.282, 0.929	0.123, 0.675
Number of data pairs	60	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.001	

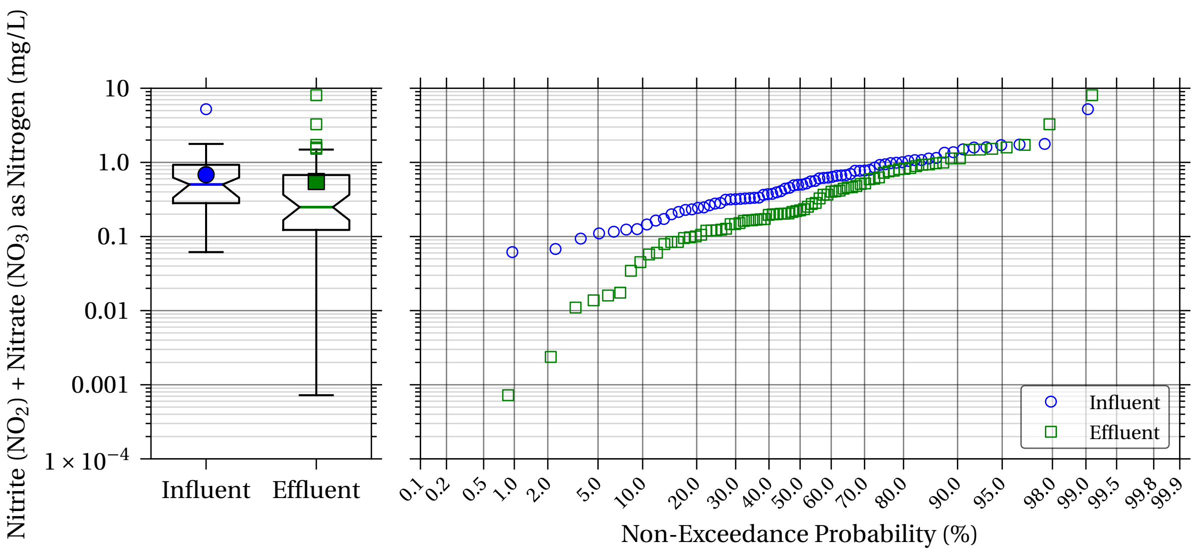


Figure 9.3: Box and Probability Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Wetland Basin BMPs

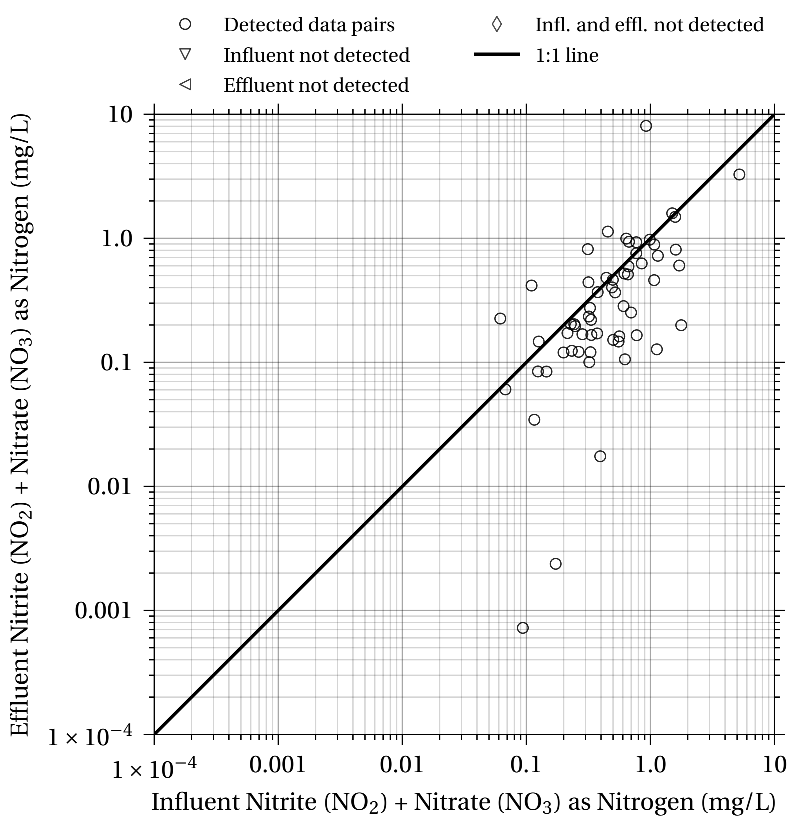


Figure 9.4: Influent vs. Effluent Plots of Nitrite (NO_2) + Nitrate (NO_3) as Nitrogen at Wetland Basin BMPs

9.3 NO_3 or NO_3/NO_2

Table 9.3: Summary of NO_3 or NO_3/NO_2 at Wetland Basin BMPs

Statistic	**Inlet**	**Outlet**
Count	72	79
Number of Non-detects	0	0
Number of Studies	3	3
Min, Max (mg/L)	0.0616, 5.22	0.000723, 8.06
Mean (mg/L) (95% confidence interval)	0.683 (0.533, 0.848)	0.555 (0.359, 0.777)
Standard Deviation (mg/L)	0.666	0.926
Geometric Mean (mg/L) (95% confidence interval)	0.478 (0.394, 0.586)	0.238 (0.169, 0.326)
Geometric Standard Deviation (mg/L)	2.34	4.33
Coefficient of Variation	1.02	1.8
Skewness	3.93	5.66
Median (mg/L) (95% confidence interval)	0.505 (0.332, 0.628)	0.249 (0.166, 0.368)
25^{th}, 75^{th} percentiles (mg/L)	0.282, 0.929	0.123, 0.675
Number of data pairs	60	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.001	

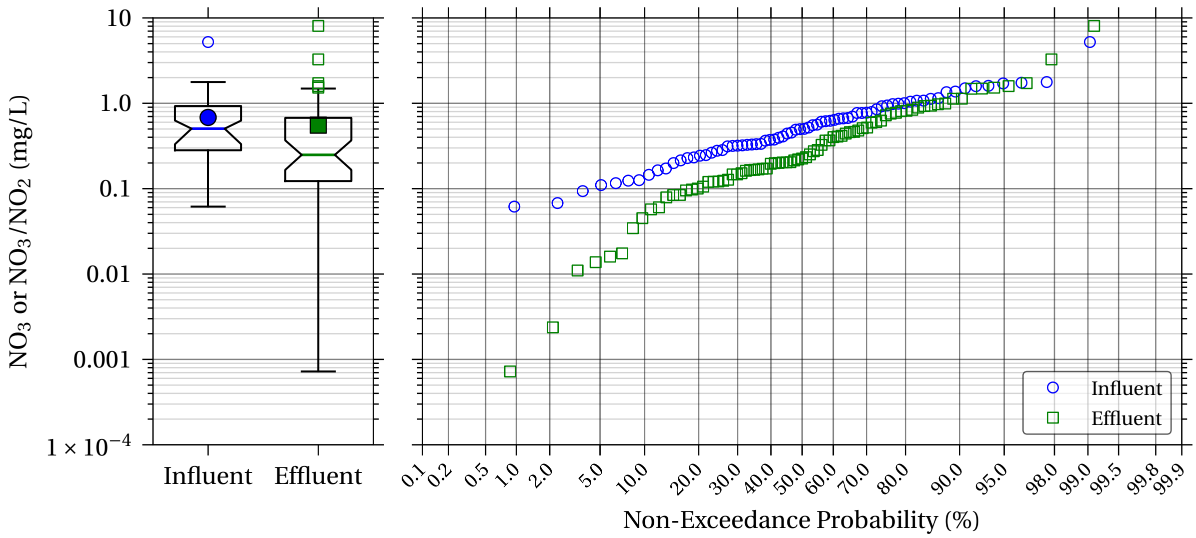


Figure 9.5: Box and Probability Plots of NO_3 or NO_3/NO_2 at Wetland Basin BMPs

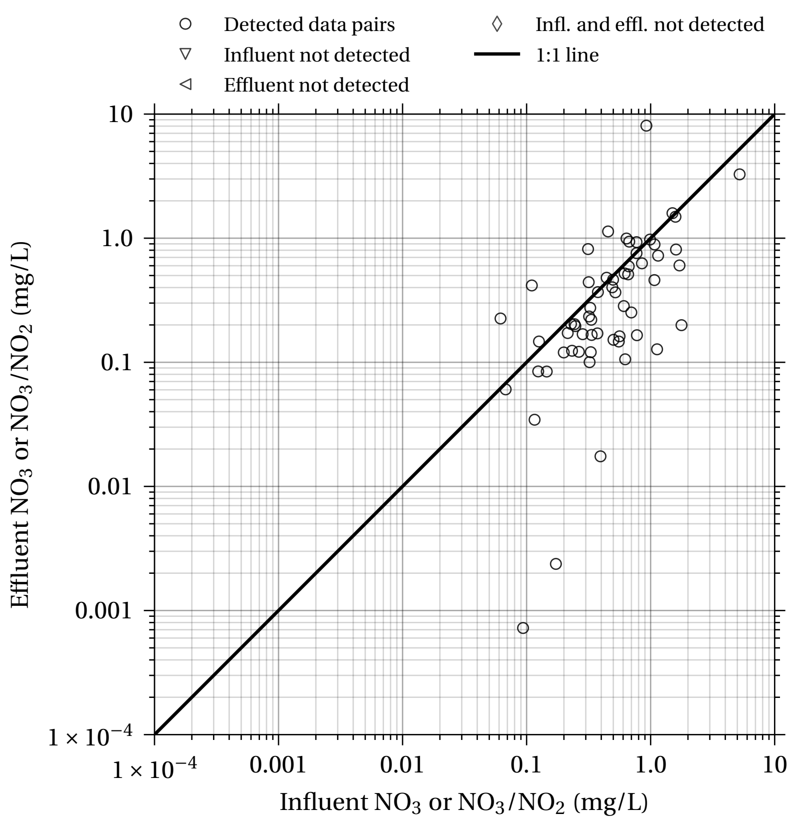


Figure 9.6: Influent vs. Effluent Plots of NO_3 or NO_3/NO_2 at Wetland Basin BMPs

9.4 Total Nitrogen

Table 9.4: Summary of Total Nitrogen at Wetland Basin BMPs

Statistic	Inlet	Outlet
Count	98	100
Number of Non-detects	0	0
Number of Studies	3	3
Min, Max (mg/L)	0.0104, 7.36	0.00657, 51.4
Mean (mg/L) (95% confidence interval)	2.03 (1.77, 2.31)	2.74 (1.64, 4.07)
Standard Deviation (mg/L)	1.36	6.0
Geometric Mean (mg/L) (95% confidence interval)	1.48 (1.2, 1.82)	1.29 (0.999, 1.65)
Geometric Standard Deviation (mg/L)	2.85	3.48
Coefficient of Variation	0.676	2.35
Skewness	1.57	5.99
Median (mg/L) (95% confidence interval)	1.88 (1.48, 2.04)	1.4 (1.04, 1.7)
25^{th}, 75^{th} percentiles (mg/L)	1.06, 2.52	0.837, 2.27
Number of data pairs	84	
Wilcoxon p-value	0.007	
Mann-Whitney p-value	0.043	

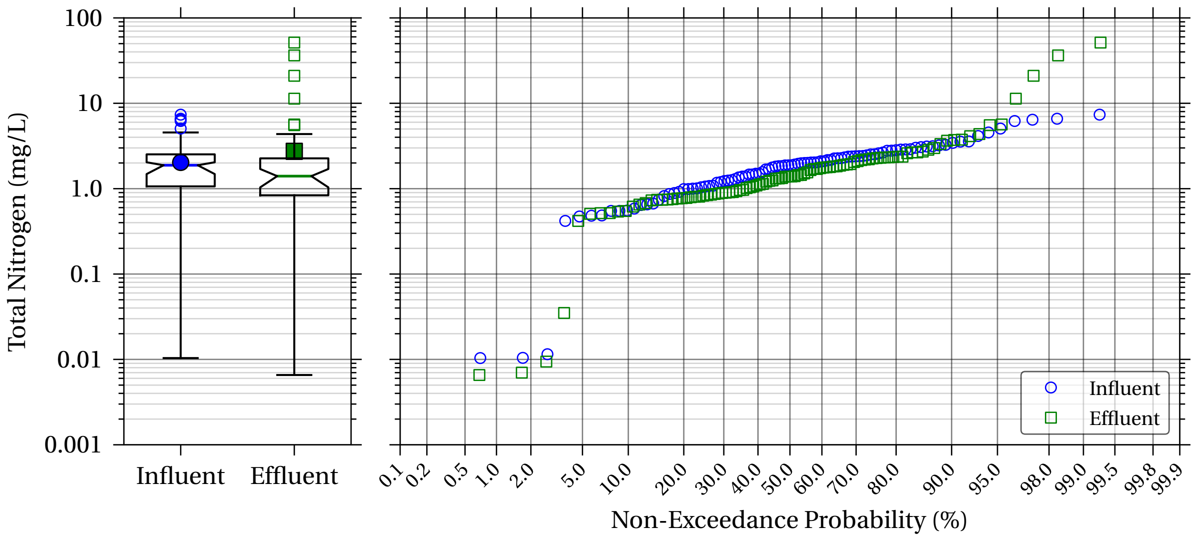


Figure 9.7: Box and Probability Plots of Total Nitrogen at Wetland Basin BMPs

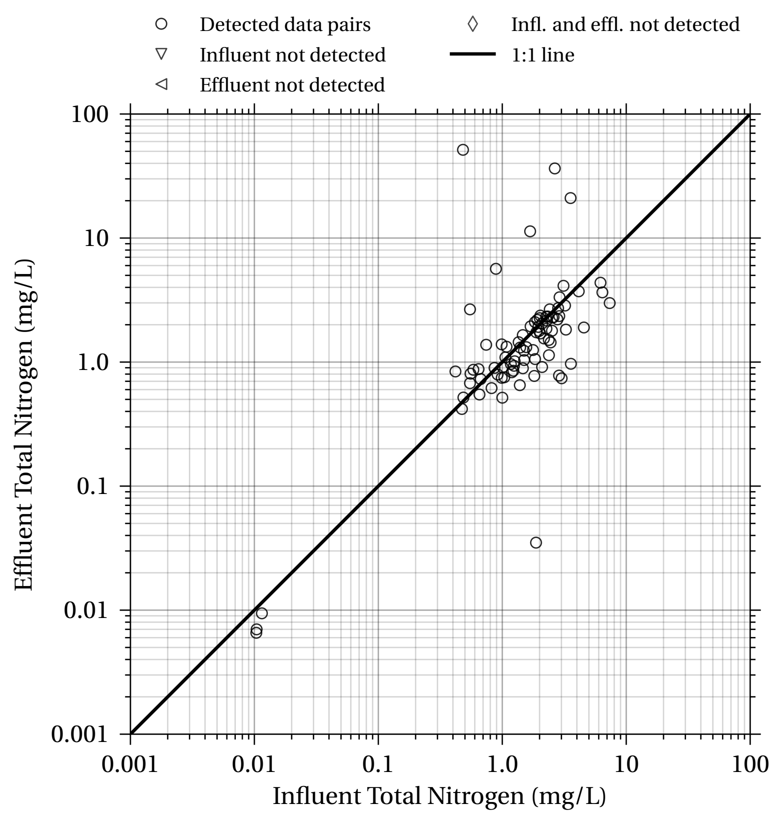


Figure 9.8: Influent vs. Effluent Plots of Total Nitrogen at Wetland Basin BMPs

9.5 Total Phosphorus

Table 9.5: Summary of Total Phosphorus at Wetland Basin BMPs

Statistic	**Inlet**	**Outlet**
Count	111	112
Number of Non-detects	0	0
Number of Studies	4	4
Min, Max (mg/L)	0.00999, 2.19	0.001, 1.44
Mean (mg/L) (95% confidence interval)	0.215 (0.17, 0.263)	0.167 (0.13, 0.205)
Standard Deviation (mg/L)	0.244	0.195
Geometric Mean (mg/L) (95% confidence interval)	0.146 (0.125, 0.172)	0.101 (0.0836, 0.123)
Geometric Standard Deviation (mg/L)	2.33	2.78
Coefficient of Variation	1.18	1.2
Skewness	4.72	3.22
Median (mg/L) (95% confidence interval)	0.138 (0.112, 0.161)	0.0906 (0.0749, 0.106)
25^{th}, 75^{th} percentiles (mg/L)	0.0854, 0.254	0.0554, 0.208
Number of data pairs	91	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.004	

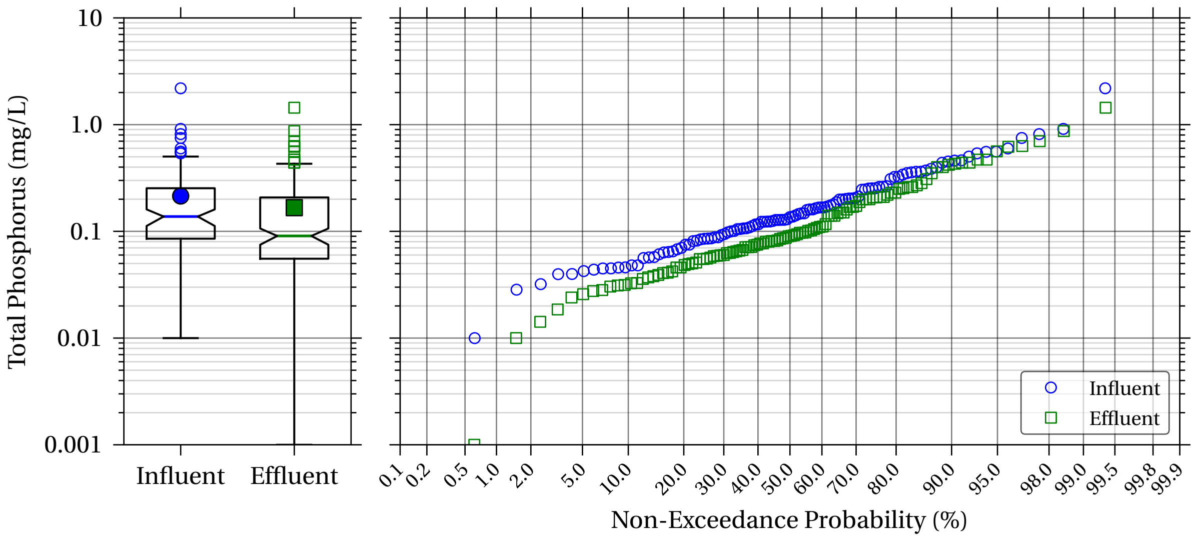


Figure 9.9: Box and Probability Plots of Total Phosphorus at Wetland Basin BMPs

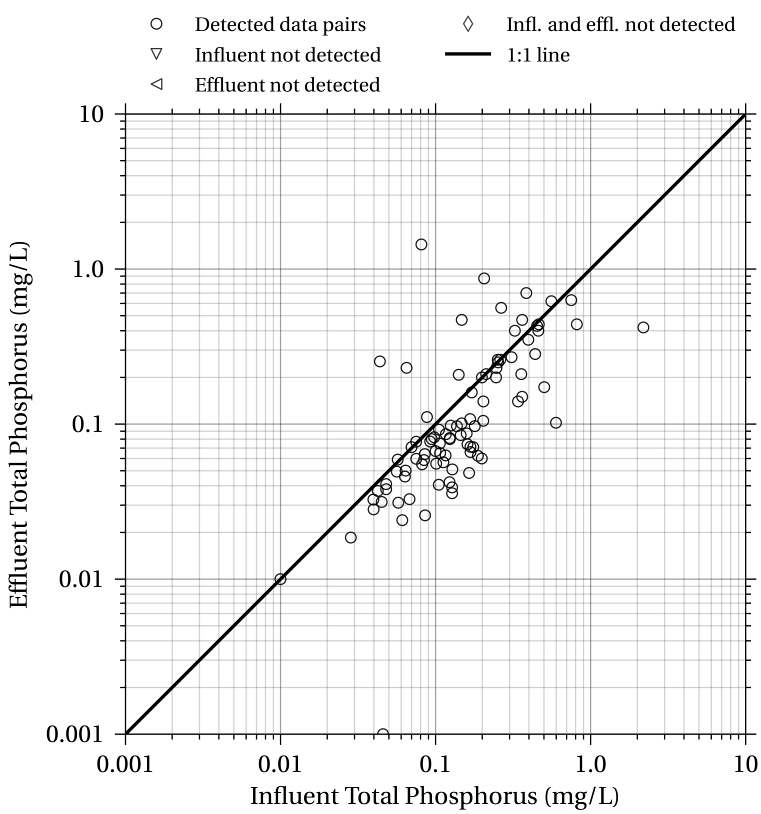


Figure 9.10: Influent vs. Effluent Plots of Total Phosphorus at Wetland Basin BMPs

9.6 Dissolved Phosphorus

Table 9.6: Summary of Dissolved Phosphorus at Wetland Basin BMPs

Statistic	Inlet	Outlet
Count	104	103
Number of Non-detects	0	1
Number of Studies	4	4
Min, Max (mg/L)	0.00853, 2.01	0.00189, 1.24
Mean (mg/L) (95% confidence interval)	0.123 (0.0896, 0.166)	0.11 (0.077, 0.144)
Standard Deviation (mg/L)	0.193	0.173
Geometric Mean (mg/L) (95% confidence interval)	0.0743 (0.0617, 0.0894)	0.046 (0.0354, 0.0592)
Geometric Standard Deviation (mg/L)	2.6	3.73
Coefficient of Variation	1.7	1.62
Skewness	7.09	3.57
Median (mg/L) (95% confidence interval)	0.0779 (0.0537, 0.0915)	0.0408 (0.0281, 0.0503)
25^{th}, 75^{th} percentiles (mg/L)	0.0433, 0.128	0.0185, 0.125
Number of data pairs	86	
Wilcoxon p-value	<0.001	
Mann-Whitney p-value	0.002	

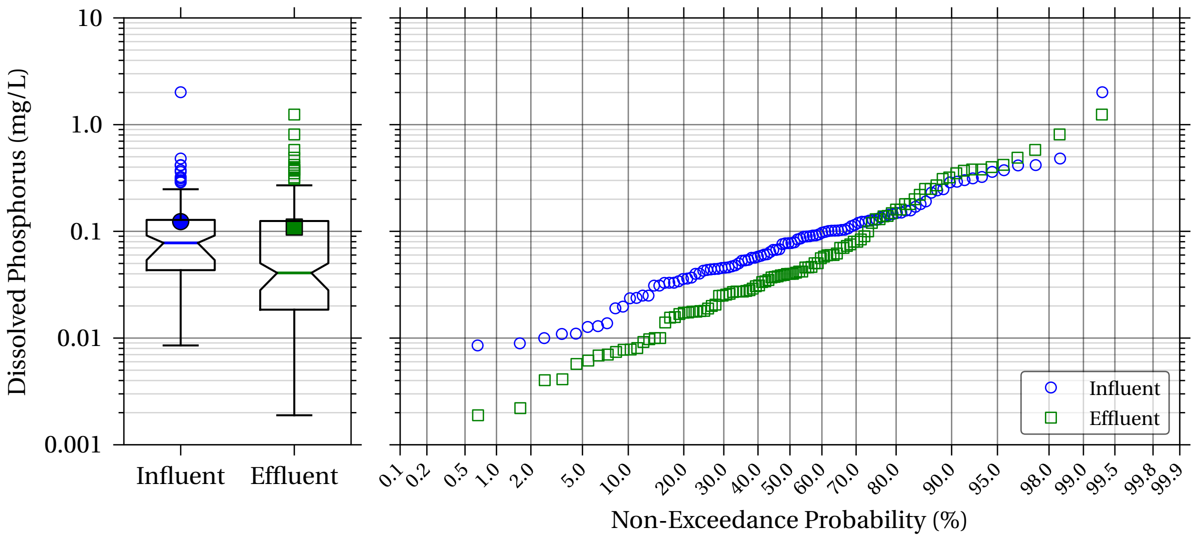


Figure 9.11: Box and Probability Plots of Dissolved Phosphorus at Wetland Basin BMPs

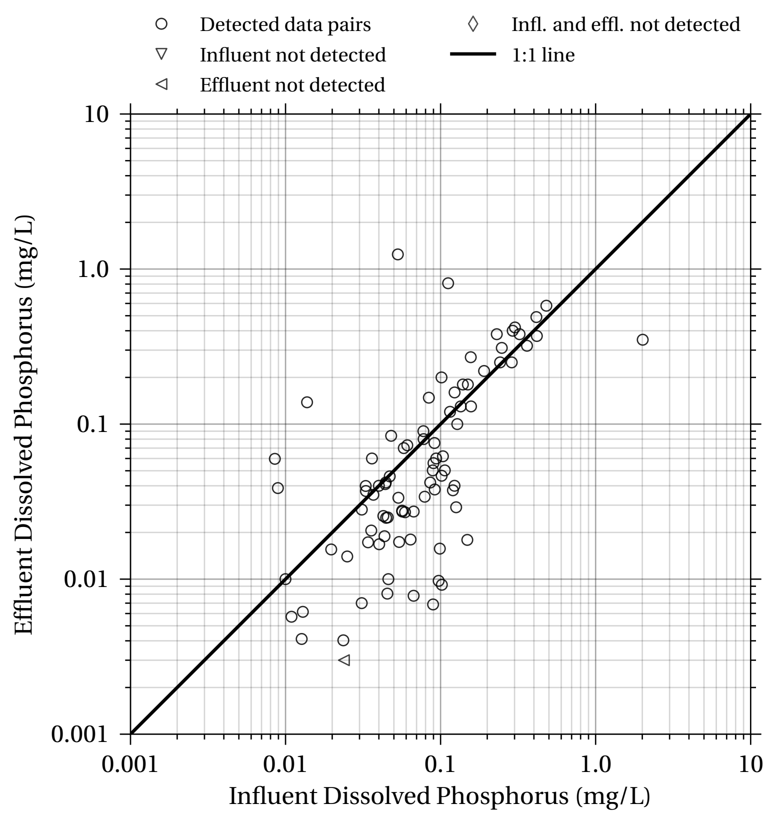


Figure 9.12: Influent vs. Effluent Plots of Dissolved Phosphorus at Wetland Basin BMPs