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Final Report
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Municipal Monitoring of Stormwater: A Comparison of Stormwater Runoff Nutrient Analysis to Permit-Required Testing

ABSTRACT

Stormwater runoff is a significant cause of pollution to waterways and is becoming an increasing concern as areas continue to urbanize and increase their quantity of impervious cover. This pollution is currently regulated by the National Pollutant Discharge Elimination System, overseen by the Environmental Protection Agency and implemented at the state level. The effectiveness of this management scheme for regulating stormwater runoff pollution is little understood. Many current systems, including the system historically and currently in place in the state of Connecticut, require regular testing of storm sewer outfalls. These results are self-reported by municipal separate storm sewer systems (MS4s) and industrial facilities to state governments. In this study, five sites with particularly high or low nutrient concentrations were identified, and autosamplers were set up at these outfalls in central and eastern Connecticut from May 2019-December 2019. Samples were collected at regular intervals throughout the duration of storm events. These samples were then analyzed for Total Nitrogen (TN) and Total Phosphorus (TP), Nitrite (NO_2^-) and Nitrate (NO_3^-) as well as conductivity levels. The analyzed sample data was then compared to the data reported historically from the MS4s using a T-test. Significant differences were found at all five sample sites. Significant differences were found in TN, TP, NO_2^- & NO_3^-, and conductivity levels. Nutrient concentrations measured in this study were generally lower than previously-measured concentrations, especially for sites that were identified as "high-nutrient" based on previous data.

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INTRODUCTION

As cities continue to expand and land use continues to change, urbanized areas are facing an increasing number of challenges with urban runoff, or stormwater, from storm events. As stormwater from precipitation flows across impervious surfaces, the water becomes contaminated with a number of pollutants that are eventually transported over ground or, eventually, underground through the storm sewer system. This runoff can carry many chemical, physical, and biological contaminants that negatively impact the water quality of the receiving waters (Pitt et al., 1995; Zgheib et al., 2012). Research has provided evidence that urban stormwater pollution has harmful effects on ecosystem health and the biotic community (Meyer et al., 2005; Walsh et al., 2005a). In addition to the negative effects on stream ecosystems, urban stormwater runoff also has negative impacts on human health and local economies, as contaminated discharges can lead to beach closures or declining fisheries stocks (Mallin et al., 2016).

In recent years, studies have demonstrated that stormwater is the leading cause of pollution in many local water systems (Walsh et al., 2005b). To effectively manage this hazard, accurate measurements are needed of contaminant levels in stormwater runoff. Finding a way to measure pollutant levels has proven to be challenging due to a number of factors that can affect the pollutant concentration. Research has shown that pollutant concentration is subject to variability depending on season, location, and other factors (Ki et al., 2011). Many previous studies have been conducted on the seasonality and intensity of rainfall events and how this may impact the quality of stormwater runoff. This includes the "first flush" phenomenon which is characterized by higher concentrations of pollutants being present during the beginning of a rainfall event or the first rainfall event after a dry period. The first flush phenomenon is thought to be dependent on a variety of factors, including time since the last antecedent wet day and storm magnitude (Bertrand-Krajewski et al., 1998; Lee et al., 2002). The extent to which the first flush phenomenon affects stormwater pollutant concentrations has been widely studied, with some estimates as high as 90% of an event's total pollutant load being transported in the first half inch of runoff (Bertrand-Krajewski et al., 1998), although this figure has been questioned in more recent studies (Bach et al., 2010). This extreme variability in pollutant loading both between storm events and within a storm event makes accurately measuring stormwater quality extremely challenging.

Stormwater discharges are difficult to manage not only because of the variability in storm events, but also due to the nonpoint source nature of the pollution. The current ability to manage urban stormwater discharges relies on permitting industrial facilities and municipalities as sources of pollution through the federal Clean Water Act (CWA). The specific permit mechanism is the National Pollutant Discharge Elimination System, or NPDES (Lee and Stenstrom, 2005). Under this permit, three potential types of stormwater sources are identified for regulation: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. Although the NPDES Stormwater Permitting System has been in place since the 1990s, little evaluation has been done to assess the accuracy of the monitoring system. Assessments that have been made in the past have largely focused on program enrollment or completeness of data submitted to the appropriate regulatory authorities (Lee and Stenstrom, 2005; Abdullah et al., 2017).

In most cases, the regulating authority for stormwater discharges is the state. Under the current provision in Connecticut, industrial facilities and municipalities must sample representative storm events at certain outfalls throughout the year on a semi-annual (industrial permittees) or other regular basis depending on the Stormwater Management Pollution and Prevention Plan in place (MS4s), (Connecticut, 2016a, b). The results of this testing, which tests for a variety of pollutants depending on the waterway impacted, are submitted to the Connecticut Department of Energy and Environmental Protection to ensure compliance. Instruction in the permit is given to test during one "wet weather" period and one "dry weather" period. For the "wet weather" monitoring, samples must be taken at least 48 or 72 hours from a previous storm (this changed throughout reissuance of permit) event and within six hours of the beginning of the storm event (Connecticut, 2016b). Aside from these specifications, little other instruction is given on sampling runoff during a given event. Below is a summary of past and current NPDES stormwater permits in Connecticut.

Permit Year	Outfalls monitored	Parameters	Methods	Frequency	Storm Event Requirements
2004, 2009, 2013	6 per town (two industrial, two commercial, two residential)	pH , Hardness, Conductivity, Oil and grease, Chemical Oxygen Demand, Turbidity, Total Suspended Solids, Total Phosphorous, Ammonia, Total Kjeldahl Nitrogen, Nitrate plus Nitrite Nitrogen , E. coli	methods prescribed in Title 40, CFR, Part 136	All 6 annually	- At least .1 inch event - 72 hours from last measurable event (2004,2009) -48 hours from last measurable event (2013) - Grab Sample - First 6 hours of storm
2017	Any outfalls discharging to impaired waterways after screening for contaminants, then 6 top outfalls	Nitrogen, Phosphorus, E. Coli, "Other pollutants of concern"	Portable meter, Methods prescribed in Title 40, CFR, Part 136	Each outfall at least once during permit term, then annually for 6 selected	-discharges resulting from any rainstorm that produces a discharge from the outfall -48 hours from last measurable event -Grab sample -First 6 hours of storm

TABLE 1: SUMMARY OF NPDES PERMIT REQUIREMENTS FOR THE STATE OF CONNECTICUT

Managing the risks of pollution associated with stormwater runoff is of particular interest to the State of Connecticut due to the state's urban landscape, amount of precipitation, and proximity to major and/or impaired waterways (Connecticut, 2017). In Connecticut's 2016 Integrated Water Quality Report, the Department of Energy and Environmental Quality (DEEP) specified stormwater runoff from nonpoint sources to be an area that still requires significant attention (Connecticut, 2017).

My research examines the variability of the reported data based on the monitoring requirements of the previous Stormwater Permit structure on water quality on specific water systems in the state of Connecticut. My research assesses the variability of stormwater runoff quality both within and across storm events. My study collected stormwater samples from May to December of 2019, throughout multiple storm events at five locations in central and eastern Connecticut.

After these samples were collected, they were analyzed for conductivity, Nitrite (NO_2^-) & Nitrate (NO_3^-), total nitrogen (TN) , and total phosphorus (TP) and compared to historical data provided to the Connecticut Department of Energy and Environmental Protection (DEEP) by specific municipalities (MS4 permittees) from 2004-2016 By comparing the data collected to the data provided to the Connecticut DEEP, my research shows that there is a significant difference between the concentrations reported to DEEP and the samples that I analyzed.

Problem Statement:

Given the variability of storms and lack of detailed instructions in current stormwater permits, is the current testing protocol effective at monitoring pollutant concentration levels at representative outfalls?

Hypothesis:

If the current testing required by stormwater permits is accurate, I would expect representative outfalls to show similar pollutant levels when I collected and analyzed additional samples. That is, outfalls that have historically tested high in total nitrogen, nitrate, total phosphorus, and conductivity should continue to show high concentrations of these pollutants and vice-versa for representative low concentration outfalls.

Significance of Research:

While research on stormwater runoff pollution concentrations has been done in the past, there is little research for the Northeast region of the United States. Similarly, data from NPDES Permits has not been analyzed in Connecticut or similar states. Many studies that have been conducted were in arid environments and have not considered the impacts of winter storm events.

Additionally, little has been done by third party observers to measure the accuracy of the NPDES Permit structure. Existing studies on government permitting structures have been done on Spill Prevention Control and Countermeasure plans and spill reporting (Abdullah et al., 2017). Even when assessing this data, the researchers looked exclusively at data that had been reported to the government. Little has been done to verify the submitted data is accurate by a third party conducting similar analyses.

If my hypothesis is confirmed – that is, if outfalls identified as high in pollutants through municipal sampling are confirmed to be highly polluted by my more-detailed sampling – then municipal sampling databases can potentially be useful for identifying high-priority areas for pollution abatement. If, on the other hand, "high" outfalls subsequently prove to have lower concentrations, then the usefulness of the municipal sampling efforts is questionable.

METHODOLOGY

My research focuses on two data sets, one of historical data that has been self-reported to the Connecticut Department of Energy and Environmental Protection and one that I collected independently from a subset of these outfalls.
The historical data from Connecticut DEEP has been aggregated from annual reports from MS4s from time frames spanning 2004-2016. This data has been scrubbed for accuracy and used to select outfall sampling sites.

Site Selection

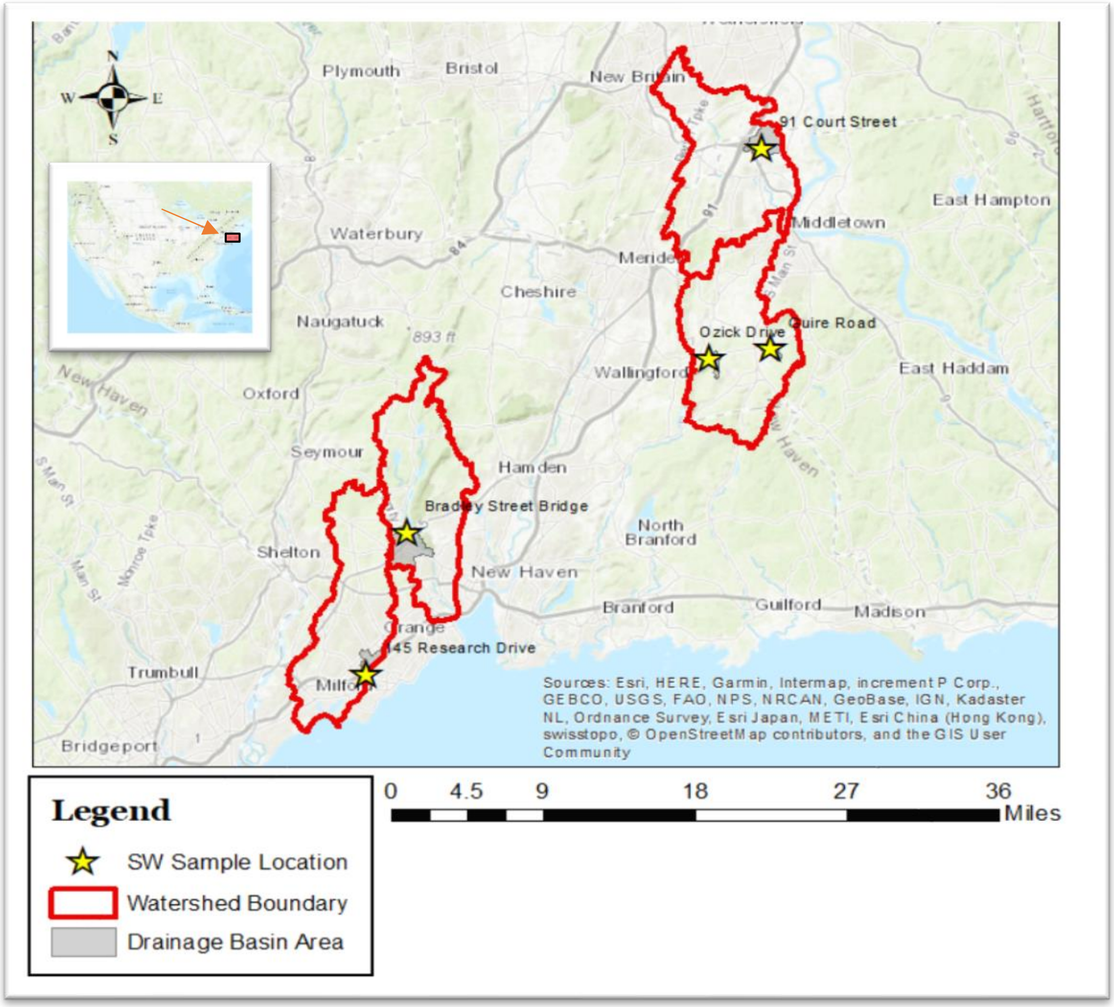
After receiving data for MS4 stormwater testing results from DEEP, the data were scrubbed for redundancies and inaccuracies. After removing clear errors and standardizing site naming conventions, I was left with 763 unique outfall locations that had been sampled three or more times. Total Nitrogen (TN) content was used as the determining criteria for selecting sites. Total Nitrogen was not a required test during this permit period, but data existed for Total Kjeldahl Nitrogen (TKN), ammonia, and nitrate-nitrite. Therefore, TN was determined by adding together nitrate-nitrite and TKN. The resulting data for TN was compiled and the concentration percentiles were:

Percentile	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**
TN (mg/L)	0.85	1.02	1.33	1.85	2.51	3.38	4.59	9.40

Sample locations were selected based on several criteria: "high" (75 percentile or above) or "low" (25 percentile or below) TN concentrations; proximity to New Haven, CT (within 60-minute drive); the number of viable data points previously collected; accessibility; date of last sample collected; and cooperation of the municipality in providing permission to sample. Using these criteria, five total sites were selected in the towns of Cromwell, Durham, Woodbridge, and Milford. A summary of the geographic context of these sites can be seen below.

SW Sample Location	Town	Watershed	MS4 Data Collection Date Range	Number of MS4 Samples Collected	TN for MS4 Data (Min)	TN for MS4 Data (Median)	TN for MS4 Data (Mean)	TN for MS4 Data (Max)
High TN Concentrations								
Cromwell, 91 Court Street	Cromwell	Mattabesset River	July 2006-April 2015	7	1.91	4.7	3.47	5.67
Milford, 145 Research Drive	Milford	Indian River	December 2004-July 2015	8	1.64	3.73	2.9	4.46
Low TN Concentrations								
Woodbridge, Bradley Street Bridge	Woodbridge	West River	November 2004 – December 2015	10	0.37	1.2	1.26	2.82
Durham, Guire Road	Durham	Mattabassett	November 2006-December 2015	11	0.54	1.18	1.18	1.76
Durham, Ozick Drive	Durham	Mattabesset	November 2006-December 2015	11	0.43	1.2	0.96	1.39

Table 2: Stormwater sampling locations and summary MS4 data.



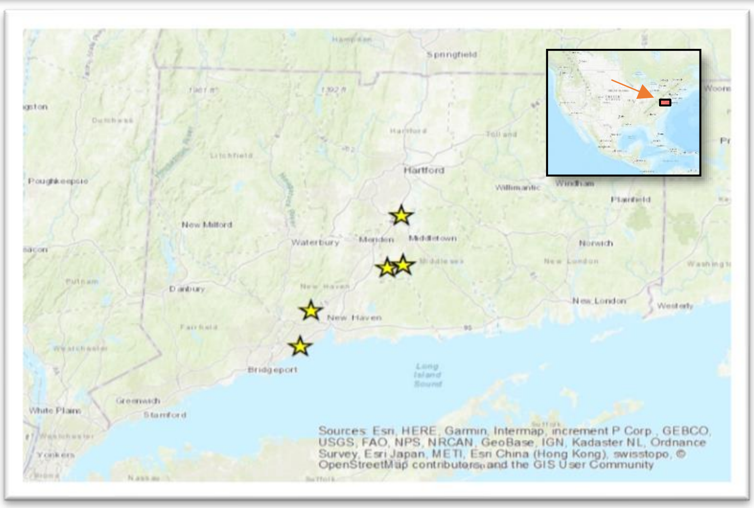


Figure 1: Map of stormwater sampling locations, their watersheds, and basin boundaries

Sample Collection

The above sites were sampled at various times during the period of May to December 2019 using ISCO 3700 and ISCO Avalanche programmable autosamplers. Before each storm event, autosamplers were filled with ice (for the ISCO 3700 models) or switched into refrigeration mode (ISCO Avalanches) and programmed to start drawing samples 30 minutes before the forecasted storm. The samplers drew 150 ml samples (ISCO 370) or 125 ml samples (ISCO Avalanche) every 10 minutes, compositing 6 samples per bottle for periods of continuous rainfall. At the end of the storm event, the samples were transported out on ice and processed in Greeley Lab.

To capture the "first flush" effect, the first hour of samples from each storm was saved. The rest of the samples of the storm were composited in a manner that would represent the storm in thirds (i.e. if 10 bottles of samples were collected, bottle 1 would be the first flush, bottles 2-4 would be composited, and so on). Conductivity was measured on raw samples (Orion conductivity probe), and then raw samples were filtered through 0.45 μm membrane filters. Both filtered and raw samples were frozen immediately after processing and later thawed for nutrient analysis.

Sample Nutrient Analysis:

Total Nitrogen & Total Phosphorus

The 60 ml raw samples were processed at the Yale Analytical and Stable Isotope Center (YASIC) for Total Nitrogen (TN) and Total Phosphorus (TP) using an Astoria II flow analyzer. The samples were digested and analyzed per YASIC standard operating procedures. Specifically, after thawing, 6 ml of each raw sample was pipetted into separate Teflon vials with 1.25 ml of digestion reagent. A digestion reagent was made with potassium persulfate, NaOH, and nanopure water. The samples were then processed in an autoclave for 55 minutes at 120◦ C on the liquid automatic cycle.

Once samples were brought to room temperature, they were run through the Astoria II Flow analyzer using FASPac software. Both TN and TP were analyzed in a single run. Samples were ran simultaneously with calibrants, lab blanks, field blanks, replicates, and spiked replicates for quality assurance purposes.

Nitrite (NO_2^-) & and Nitrate (NO_3^-)

The 60 ml filtered samples were analyzed for nitrite plus nitrate (hereafter referred to as NO_3^-) using a 940 Professional IC Vario ion chromatograph.

Data Analysis

The data collected from the outfalls were averaged by storm event. These averages were compared to the historical data submitted to DEEP using Student's T-Test. The data were analyzed using the software MiniTab. The null hypothesis for this research is that the two groups being compared are equal.

RESULTS

These results (Figures 2-6) include data from five sites: 91 Court Street in Cromwell, 135 Research Drive in Milford, Bradley Street Bridge in Woodbridge, Guire Road in Durham, and Ozick Drive in Durham. In total, 148 samples have been analyzed for conductivity, NO_3^-, Total Nitrogen (TN), and Total Phosphorus (TP). The mean for conductivity, NO_3^-, TN, and TP for this set of data were 352 umhos, 0.463 mg/l, 1.30 mg/l, and 63.5 µg/l, respectively. T-tests performed on each data set collected for this research versus the historical data had varying levels of significance depending on the site and the nutrient involved. A summary of significance of test results can be seen below in Table 3.

The samples also showed substantial intra-storm variability across all sites and pollutant concentrations. Preliminary results do not show apparent patterns in this variability in seasonality or time taken during the storm. This may be because my data was not collected in conjunction with flow data, making an analysis of the first flush effect difficult to measure. The right most boxplots in figures 2, 3, 4, 5, and 6 show the variability among all samples collected for each site (not averaged by storm event).

Figure 7 shows the median values of pollutant concentrations of the DEEP data compared to my data. My sites were selected based on TN concentration, and the TN concentrations appear to show a reversion to the mean. That is, low sites continued to stay low and the high sites reverted to average concentration levels. Similar trends were observed for the other nutrients that were examined, TP and NO3-. Conductivity results did not show this trend.

Site	TN	TP	NO_3-	Conductivity
High TN Concentrations				
Cromwell	x	↓	↓	x
Milford	↓	↓	x	x
Low TN Concentrations				
Woodbridge	x	x	x	↑
Durham- Guire	↓	x	x	x
Durham- Ozick	x	↓	x	x

Table 3: P-values for site t-tests based on contaminant. Cells with arrows represent significant difference, p<.05. Up arrows indicate significantly higher, down arrows indicate significantly lower.

Historic vs Current Data for Court Street, Cromwell Site (High)

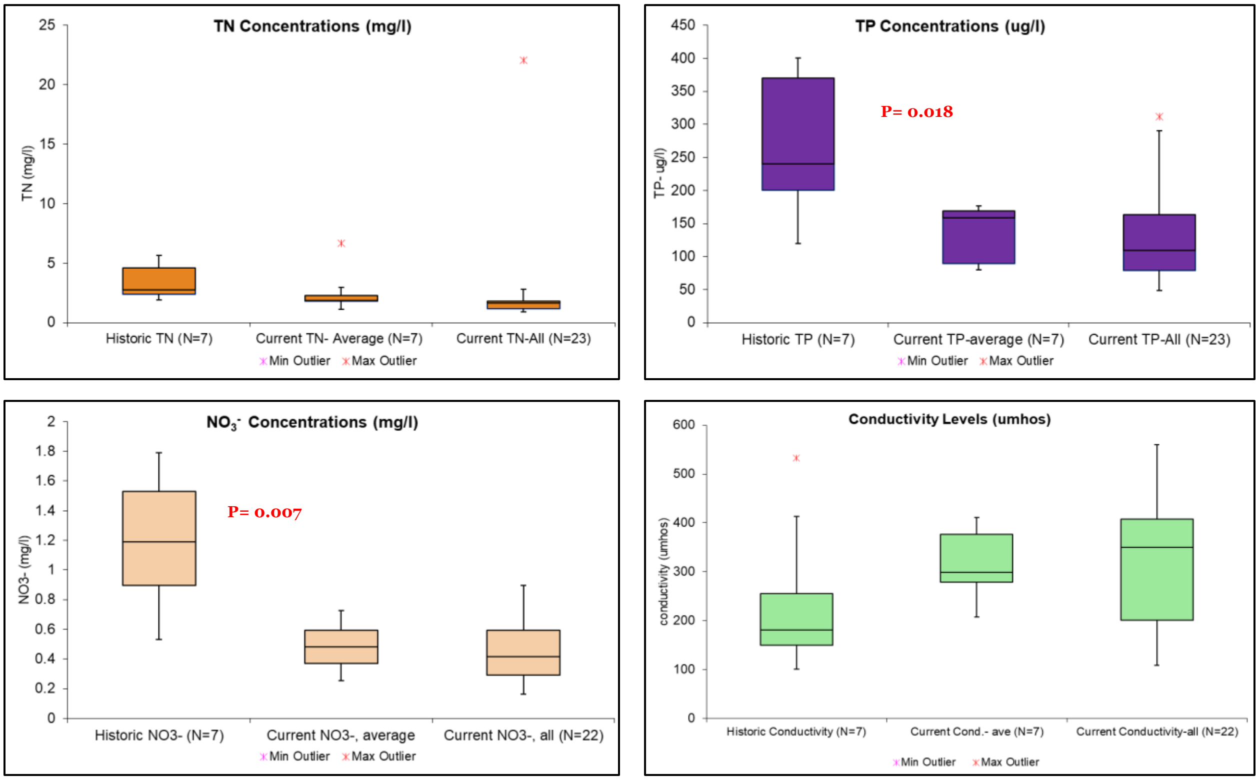


*FIGURE 2: FIGURE 2: BOXPLOT COMPARING TN, TP, NO3-, AND CONDUCTIVITY FOR CROMWELL SITE, WITH THREE CATEGORIES: HISTORIC DATA COLLECTED BY THE MUNICIPALITY AND REPORTED TO CT DEEP; MY DATA AVERAGED BY STORM; MY DATA, ALL SAMPLES. SIGNIFICANT DIFFERENCES BETWEEN THE FIRST TWO CATEGORIES ARE SHOWN WITH P VALUES. BOXES SHOW 25TH, 50TH, AND 75TH PERCENTILES. LOWER WHISKERS DEFINED BY HIGHER VALUE BETWEEN THE MINIMUM VALUE OF THE DATA SET AND Q_1- 1.5*IQR (INNER QUARTILE RANGE), UPPER WHISKERS DEFINED BY THE LOWER VALUE BETWEEN THE MAXIMUM VALUE OF THE DATA SET AND Q_3+1.5*IQR. OUTLIERS DEFINED BY VALUES OUTSIDE OF WHISKER RANGES.*

Historic vs Current Data for Research Drive, Milford Site (High)

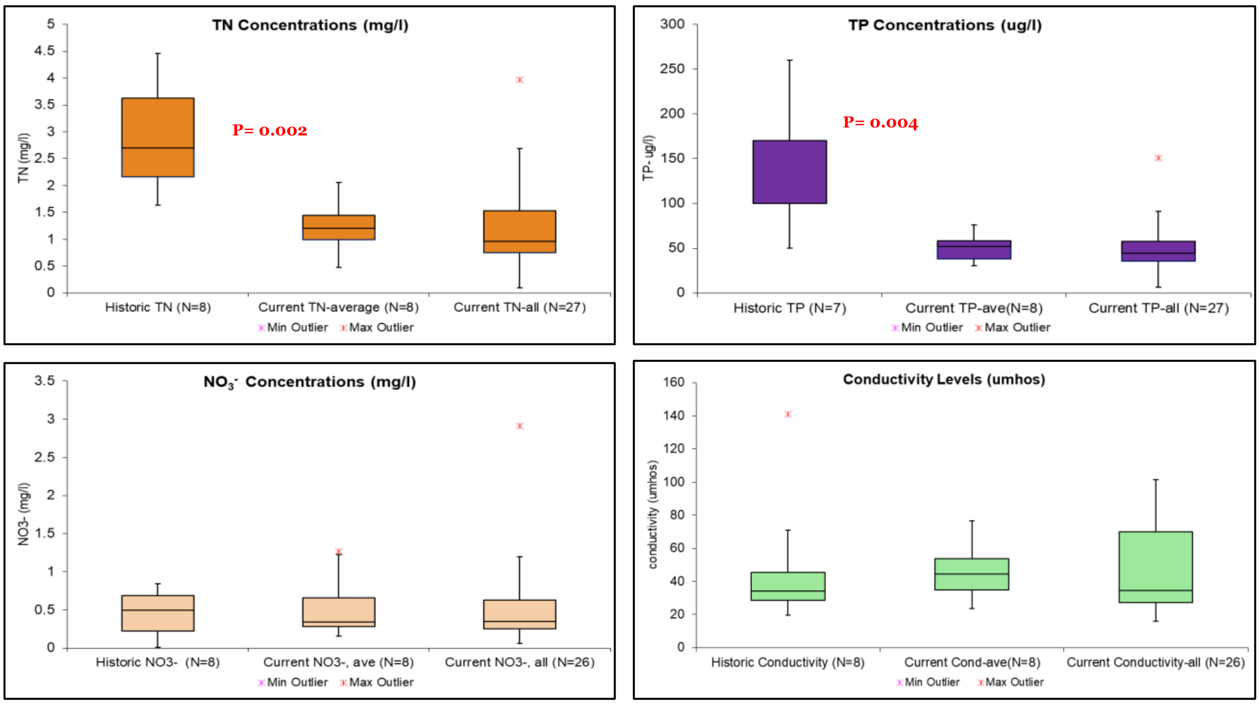


FIGURE 3: *BOXPLOT COMPARING TN, TP, NO3-, AND CONDUCTIVITY FOR MILFORD SITE, WITH THREE CATEGORIES: HISTORIC DATA COLLECTED BY THE MUNICIPALITY AND REPORTED TO CT DEEP; MY DATA AVERAGED BY STORM; MY DATA, ALL SAMPLES. SIGNIFICANT DIFFERENCES BETWEEN THE FIRST TWO CATEGORIES ARE SHOWN WITH P VALUES. BOXES SHOW 25TH, 50TH, AND 75TH PERCENTILES. LOWER WHISKERS DEFINED BY HIGHER VALUE BETWEEN THE MINIMUM VALUE OF THE DATA SET AND Q_1- 1.5*IQR (INNER QUARTILE RANGE), UPPER WHISKERS DEFINED BY THE LOWER VALUE BETWEEN THE MAXIMUM VALUE OF THE DATA SET AND Q_3+1.5*IQR. OUTLIERS DEFINED BY VALUES OUTSIDE OF WHISKER RANGES.*

Historic vs Current Data for Bradley Bridge, Woodbridge Site (Low)

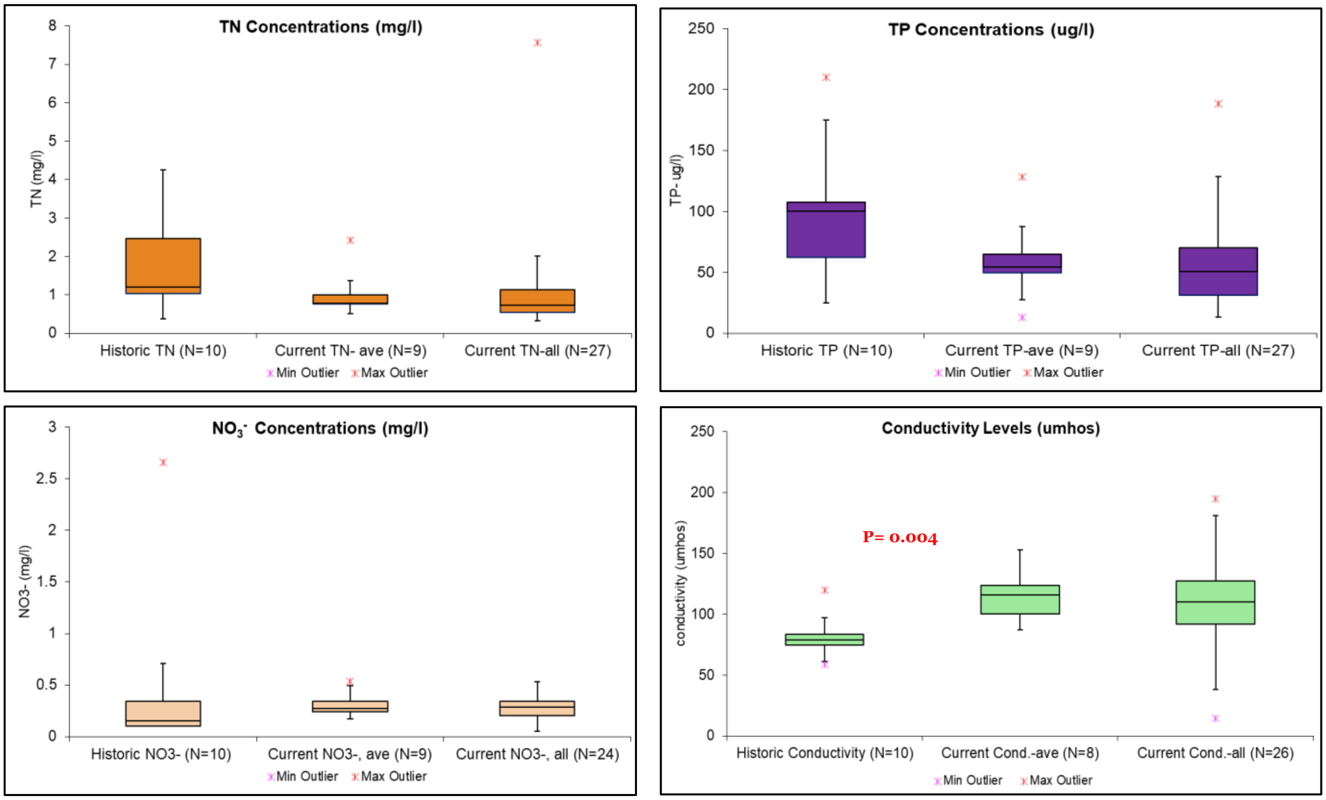


Figure 4: *Boxplot comparing TN, TP, NO3-, and conductivity for Woodbridge site, with three categories: Historic data collected by the municipality and reported to CT DEEP; my data averaged by storm; my data, all samples. Significant differences between the first two categories are shown with p values. Boxes show 25TH, 50TH, and 75TH percentiles. Lower whiskers defined by higher value between the minimum value of the data set and Q_1- 1.5*IQR (inner quartile range), Upper whiskers defined by the lower value between the maximum value of the data set and Q_3+1.5*IQR. Outliers defined by values outside of whisker ranges.*

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Historic vs Current Data for Guire Road, Durham Site (Low)

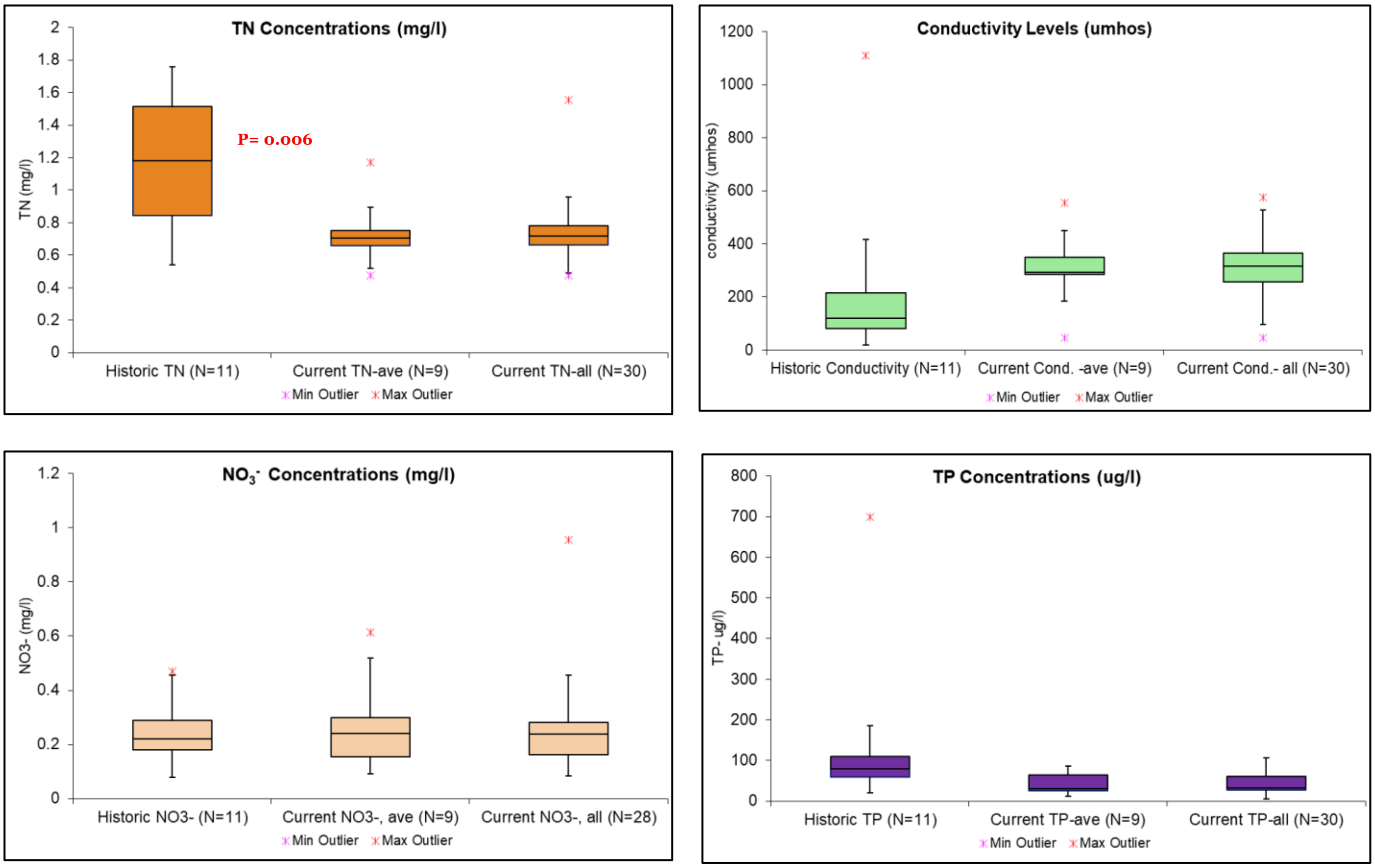

FIGURE 5: *BOXPLOT COMPARING TN, TP, NO3-, AND CONDUCTIVITY FOR GUIRE ROAD SITE, WITH THREE CATEGORIES: HISTORIC DATA COLLECTED BY THE MUNICIPALITY AND REPORTED TO CT DEEP; MY DATA AVERAGED BY STORM; MY DATA, ALL SAMPLES. SIGNIFICANT DIFFERENCES BETWEEN THE FIRST TWO CATEGORIES ARE SHOWN WITH P VALUES. BOXES SHOW 25TH, 50TH, AND 75TH PERCENTILES. LOWER WHISKERS DEFINED BY HIGHER VALUE BETWEEN THE MINIMUM VALUE OF THE DATA SET AND Q_1- 1.5*IQR (INNER QUARTILE RANGE), UPPER WHISKERS DEFINED BY THE LOWER VALUE BETWEEN THE MAXIMUM VALUE OF THE DATA SET AND Q_3+1.5*IQR. OUTLIERS DEFINED BY VALUES OUTSIDE OF WHISKER RANGES.*

Historic vs Current Data for Ozick Drive, Durham Site (Low)

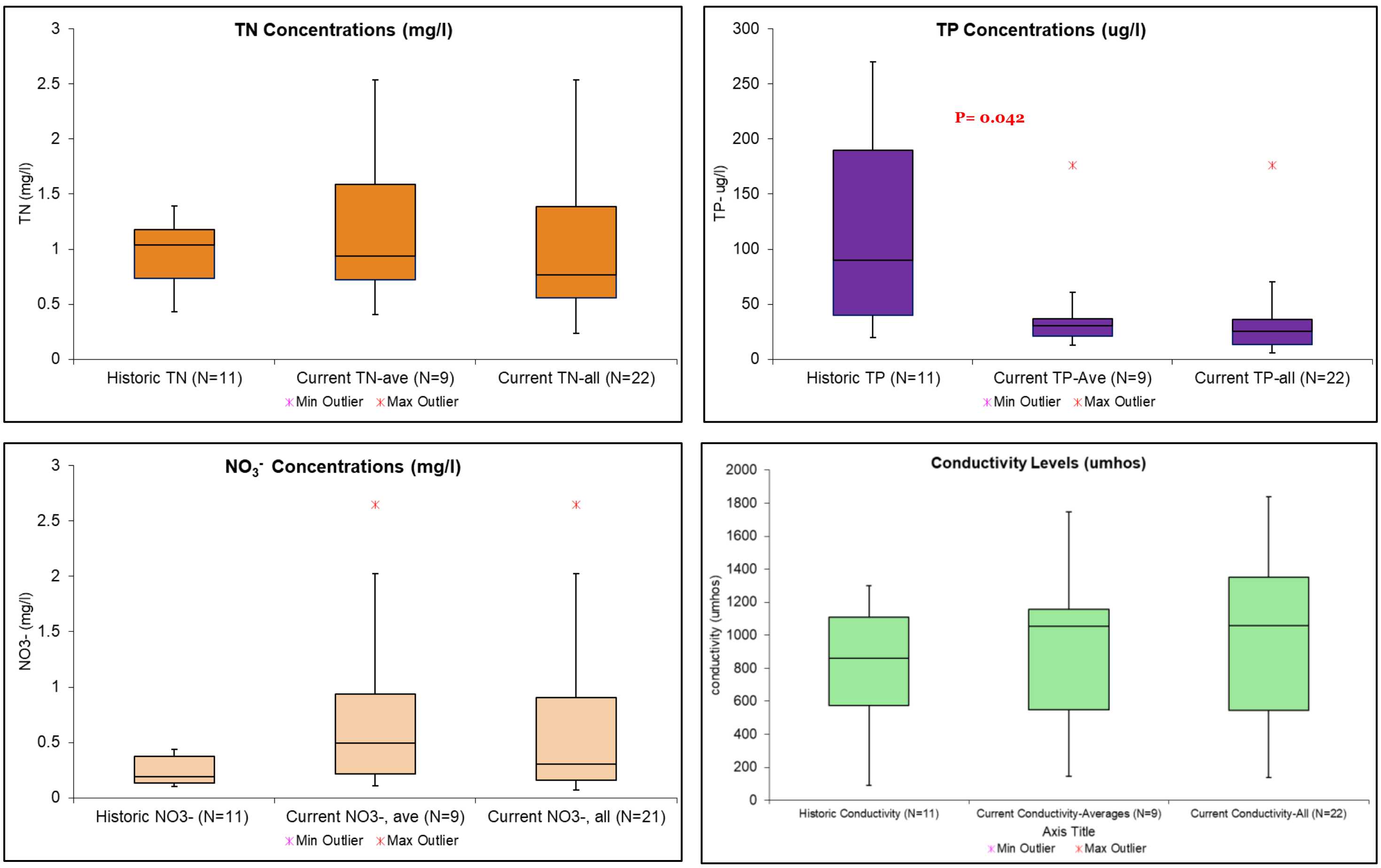

Figure 6: *Boxplot comparing TN, TP, NO3-, and conductivity for Ozick Drive site, with three categories: historic data collected by the municipality and reported to CT DEEP; my data averaged by storm; my data, all samples. Significant differences between the first two categories are shown with p values. Boxes show 25th, 50th, and 75th percentiles. Lower whiskers defined by higher value between the minimum value of the data set and $Q_1 - 1.5*IQR$ (inner quartile range), Upper whiskers defined by the lower value between the maximum value of the data set and $Q_3 + 1.5*IQR$. Outliers defined by values outside of whisker ranges.*

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Median historic contaminant levels vs median of current contaminant values

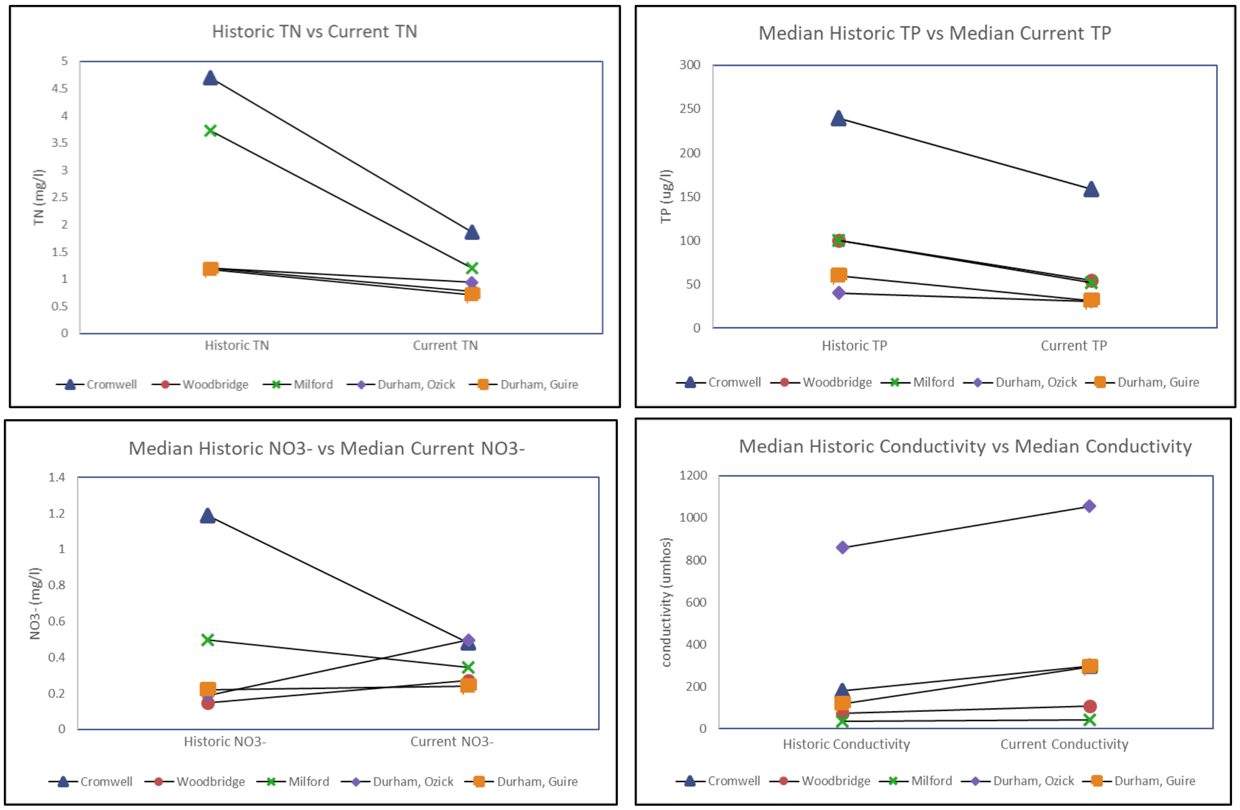

FIGURE 7: MEDIAN VALUES OF CONTAMINANTS, HISTORIC VS CURRENT

DISCUSSION

The results of my research show some differences from data that were previously reported by the MS4s. Six out of the seven significant differences represent lower pollutant levels than the historical data. The significant differences were not consistent across pollutant type or site location. Each site showed a statistical difference in at least one category. This could indicate differences that are happening within each outfall basin area.

My results do not support the hypothesis that the historical data would be similar to current data if collected in more routine, intensive testing. Because my data was collected more recently, it is possible that the significantly lower pollutant levels are due to better stormwater management practices taking place within the drainage area. However, I would expect to see significantly lower pollutant levels across all categories and sites if this were the case.

Another potential explanation for these differences could be the method of sampling and testing that was performed. My data represents composite samples, while the reported data represents grab samples. Because these samples represent one particular moment in a stormwater runoff event, it is possible that grab samples are not the most representative sampling method for stormwater analysis.

Perhaps the most likely explanation for these differences is simply reversion to the mean. That is, I specifically selected for sites with extreme values from the large number of sites in the municipal database, but these extreme values may have been a statistical fluke rather than true characteristics of these sites.

Stormwater pollution continues to be a major concern for the state of Connecticut. Currently, the stormwater permit implemented at the state level is our best way of monitoring and evaluating the contaminants that exist in urban run-off. In order to make proper management decisions regarding urban run-off, it is important that we have accurate data that represents what is truly happening in our watersheds. This research supports the hypothesis that these values can vary significantly.

Further research in this area is necessary for us to determine how to best measure our stormwater contaminant levels. Additional studies could include monitoring variables such as storm intensity and flow in addition to nutrient analysis. While this study focused primarily on nutrients, many stormwater contaminants exist and are routinely tested for. Another area of potential research would be to test for different contaminants to see if they follow similar trends.

Additionally, I believe there is opportunity for research on how these testing requirements are implemented. Understanding how testing is being conducted on the municipality level could help determine how we can be more consistent in our testing methods.

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