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Abstract

In the United States, new legislation has given regulatory authorities greater oversight of municipal stormwater management programs. However, estimating the impact of greater oversight on municipal actions is difficult due to the uncertainty in current compliance efforts and their associated costs. This paper seeks to fill this gap through a case study of NPDES stormwater runoff permit reports from municipalities in Southeast Wisconsin. Specifically, this study evaluates the reported actions and expenditures against socioeconomic variables to identify the relationships between cost, socioeconomics, and the best management practices (BMPs) used for compliance. Results indicate that there are distinct differences between municipalities with and without financial and personnel resources, clear high- and low-cost BMPs, and large variation in the practices municipalities implement to meet regulatory requirements. Furthermore, results suggest that regulators should take a flexible and pragmatic approach that considers individual municipal constraints and limitations when exercising greater regulatory authority.

Keywords
best management practices; case study; regulations; stormwater; water quality

1. Introduction

Many large-scale water quality issues, such as eutrophication and elevated pathogens, are driven by rainfall-runoff processes in the urban environment. In recognition of this, the United States federal government has included urban runoff underneath the regulatory umbrella of the National Pollutant Discharge Elimination System (NPDES),[1] developed under Section 303(d) of the Clean Water Act.[2] This system requires municipal separate storm sewer systems (MS4s) to obtain a permit for their stormwater discharge into waters of the state by implementing a stormwater management program that addresses minimum control measures to the "maximum extent practicable." This phrase – maximum extent practicable – is purposeful in that it allows states and municipalities to set their own definitions for how stormwater is managed to meet permit requirements. Flexibility in the language promotes fairness among states and municipalities that vary in size, demographics, socioeconomics, and institutional capacity, and that have unique water quality issues. This has also meant that state-level agencies tasked with enforcing NPDES have flexibility with how they administer the program and approve individual permit applications. However, to a large degree the ultimate authority to define what Best Management Practices (BMPs) are used to meet the maximum extent practicable has been vested with individual municipalities (Donald Duke and Augustenborg [4]).

The municipal autonomy to self-define which and how BMPs meet the maximum extent practicable has led to challenges by environmental groups, industry groups, and municipal organizations. These challenges culminated in a lawsuit – Environmental Defense Center v. US Environmental Protection Agency, 344 F.3d. 832 (9th Cir. 2003) (EDC) – that resulted in what is known as the MS4 Remand Rule (US EPA [19]). This new rule requires greater public participation in the permit process, and perhaps more importantly, greater regulatory oversight of the permit, which transfers ultimate approval of BMPs that meet the maximum extent practicable from the municipalities to the state regulators for Phase II MS4s (populations <100,000). Now that the bill has been signed into law, state regulators must decide to what degree and how they will exercise the authority of the MS4 Remand Rule. As a result, municipalities may face changes in how their stormwater management plans are evaluated.

These changes may impact the municipalities in different ways depending upon the municipalities' existing stormwater management program efforts, socioeconomic characteristics, or unique water quality challenges. For example, municipalities with a limited tax base may be constrained by the types of BMPs that they can implement due to their associated costs. Because of this, permit compliance actions that meet the maximum extent practicable may need to look different for different municipalities. Regulators face a significant challenge, however, in determining what factors – socioeconomic, physical, demographic, etc. – influence BMP adoption by municipalities and the appropriate way to incorporate these considerations into permit evaluations.

State regulators and municipalities would, therefore, benefit from an understanding of the extent to which maximum extent practicable has typically been defined and the factors that contribute to BMP adoption. To this end, existing studies have evaluated the factors that influence the local-level implementation of NPDES compliance (White and Boswell [23]; Aguilar and Dymond [2]), the impact of governance structures on stormwater management (Porse [15]), and differences among high-performing and low-performing stormwater programs (Morison and Brown [12]); however, none have evaluated compliance in the context of increased regulatory oversight, or evaluated the cost of complying with individual minimum control measures. This is important, as the financial burden of stormwater regulations is uncertain (Allerhand *et al*. [1]) and has long been a major reason for a lack of compliance (NRC [13]).

Determining this cost is not a straightforward task, as the implementation of BMPs can vary widely depending upon the nature of the practice. For example, Pollution Prevention is a minimum control measure that can be addressed through street sweeping (US EPA [20]), but the cost of doing so may vary widely depending upon the cost of equipment and personnel, the frequency of sweeping, and type of street sweeping truck, among other factors. This means there is not a straightforward and reliable method to determine the cost of many BMPs. Therefore, there is a need for research that can meet this challenge and provide insights into the cost of BMPs used for regulatory compliance, as well as the factors that contribute to BMP adoption.

In this study, we seek to fill this gap through a case study of NPDES reports in southeast Wisconsin that evaluates relationships between cost, socioeconomics, and the BMPs used for regulatory compliance. Specifically, this study seeks to (1) summarize and evaluate the BMPs used by municipalities in Southeast Wisconsin to meet the minimum control measures set forth by the state; (2) determine whether socioeconomic indicators are correlated with the adoption of certain BMPs; (3) evaluate the cost of compliance against BMPs reported; and (4) explore how these municipalities might be impacted by the MS4 Remand Rule. Ultimately, this information can be used by regulators who are interested in understanding what contributes to municipal stormwater management actions, as well as municipalities that seek to understand how they might need to adapt to changes in stormwater regulations.

2. Methodology

2.1. Case study region – southeast Wisconsin

The region for this analysis is the southeast WDNR district of Wisconsin (Figure 1). This area covers 3,200 square miles and contains 85 separate cities and villages that have applied to the WDNR for a discharge permit for their stormwater. Of these municipalities, 6 qualify as Phase I (i.e., populations >100,000) and the remainder qualify as Phase II MS4s. This region was chosen for analysis because it contains the largest number of municipalities within a single WDNR district and had the most available permit data for the districts. It is also the most diverse region with municipalities that vary in size, demographics, and economics (Table 1). As such, it presents an accessible and representative sample of municipalities from which to evaluate compliance with NPDES regulations.

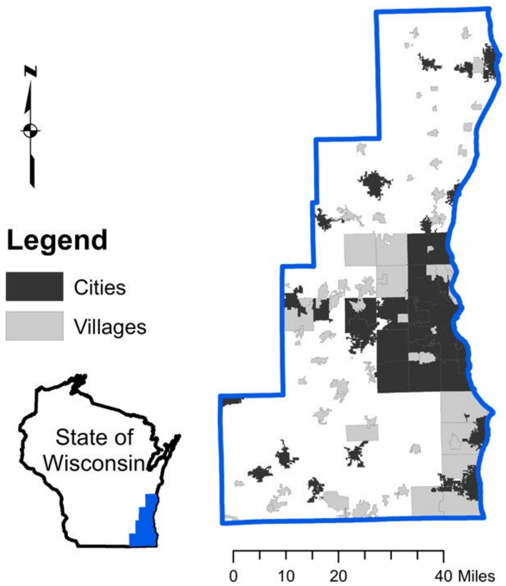

Figure 1. City and village MS4s within the case study area of southeast Wisconsin, USA.

Table 1. Municipalities summary.

	Min	Median	Max
Size (mi^2)	0.02	13.2	96.6
Population	185	11,605	951,448
Median household income	30,173	66,594	156,250
Race white alone, not hispanic or latino (%)	52	91	98

2.2. Requirements of the Wisconsin NPDES Program

The requirements of the NPDES Program in Wisconsin are outlined in the Wisconsin Legislative Code NR 216.07 and include the following six minimum control measures:

- *Public Education and Outreach*. Develop a program to encourage the public and businesses to improve their actions in reducing stormwater pollution.
- *Public Involvement and Participation*. Notify the public of activities related to the permit and encourage public input and participation regarding these activities.
- *Illicit Discharge Detection and Elimination*. Detect and eliminate illicit connections and discharges to the MS4.
- *Construction Site Pollution Control*. Develop and enforce a soil erosion control ordinance for construction sites.
- *Post Construction Stormwater Management*. Develop and enforce a postconstruction stormwater management ordinance that reduces stormwater pollutant runoff from new and redevelopment.
- *Pollution Prevention*. Actions to prevent pollution on municipally-owned properties including transportation infrastructure, storage yards, maintenance areas, etc.

In addition to these minimum control measures, municipalities must also (1) meet a developed urbanized area standard where they demonstrate a Total Suspended Solids (TSS) reduction of 20% using a modeling approach; (2) develop and maintain a map of the storm sewer system; and (3) implement a plan for reducing specific pollutants if the municipality discharges a pollutant of concern into an impaired water.

In response to these permit requirements, municipalities perform and report specific actions to demonstrate compliance through an annual report submitted to the WDNR. This report can take the form of a template provided by WDNR or a written format of the municipalities choosing. Regardless of form, all reports are submitted electronically in PDF version to the WDNR. These reports contain question prompts regarding institutional management (i.e., website development, personnel training, etc.), minimum control measure BMPs, TSS modeling results, inspection and enforcement actions, water quality concerns, and proposed program changes. In addition, municipalities are encouraged to include their annual budget and expenditures, itemized over nine categories that include Public Education and Outreach, Public Involvement and Participation, Illicit Discharge Detection and Elimination, Construction Site Pollution Control, Post Construction Stormwater Management, Pollution Prevention, Stormwater Quality Management, outfall map, and other.

2.3. NPDES report and socioeconomic database

The PDF reports submitted by the 85 municipalities in Southeast Wisconsin served as the source for the NPDES compliance data evaluated in this study. From these reports, 47 items were cataloged, resulting in 119 categorical and 33 numerical variables. In addition, 83 socioeconomic variables were obtained from census data (factfinder.census.gov) and integrated into the database. This includes information related to population, demographics, housing, and economics. Once compiled, the database was used to assess the current state of compliance in Southeast Wisconsin. Best Management Practices and expenditures for each individual minimum control measure were cataloged and summarized to identify commonly adopted BMPs, BMPs that might be underutilized, and resource allocations among minimum control measures.

2.4. Statistical analysis of the dataset

After summarizing the BMPs across all municipalities, the dataset was assessed to identify relationships between BMPs, expenditures, socioeconomics, and other report data. All statistical analysis was performed in the statistical software package JMP 13 (SAS Institute [17]). First, response screening was performed to evaluate the strength of prediction among the large set of variables. Then, using the results from the response screening, the strength of the relationships was evaluated using either chi-squared test and odds ratio, one-way analysis of variance, or standard least squares.

For two categorical variables, such as evaluating whether a municipality that performed action 1 also performed action 2, a chi-squared test and odds ratio were computed. The Pearson's chi-squared test was performed to examine the null hypothesis that two categorical variables are independent at $\alpha = 0.05$ and represented by the following equation:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

(1)

where

X^2 is the chi-squared test statistic, O is the observed cell count and E is the expected cell count.

The odds ratio represents the likelihood or odds that outcome X will occur, given a particular outcome Y, compared to the odds of outcome X occurring in the absence of outcome Y. This scenario can be set up as a 2×2 contingency table with the odds ratio represented by the following equation:

$$OddsRatio = \frac{p_{11} \times p_{22}}{p_{12} \times p_{21}}$$

(2)

Where p_{ij} is count in the i^{th} row and j^{th} column of a 2×2 contingency table. This provides a straightforward indicator of the strength of relationship between categorical variables within the dataset.

The relationship between categorical and numerical variables was determined using one-way analysis of variance to compare the means of different samples. For example, one-way analysis of variance could determine whether municipalities that perform action A have different socioeconomic indicators (i.e., population density, average income, etc.) than those that do not. Finally, standard least squares regression was used for relationships with numerical dependent and independent variables, as represented by the following equation:

$$y = \alpha + \beta x$$

(3)

where α is the y -intercept, β is the slope, and y and x are the dependent and independent variables, respectively. The regression models were tested for all assumptions of linear regression and where those assumptions were violated, the x or y variables were transformed (e.g., log10) as appropriate. Overall, the models are useful for identifying possible trends and evaluating the strength of relationships within the database.

2.5. Methodological limitations

There are two main limitations to consider in interpreting the results of this case study. The first is the generalizability of the findings. This case study is drawn from a sample of municipalities located in Southeast Wisconsin and may not be representative of other regions in the US, or even other regions within Wisconsin. In light of this, the reader should take into consideration the characteristics of the municipalities used in this study, as well as Wisconsin's NPDES program, before interpreting how it might apply to another region. The second is the use of self-reported data. This study assumes that the information provided from the municipalities is reliable; however, there is no way to check the validity of the self-reported BMPs without on-ground truthing.

3. Results and discussion

3.1. Summary of BMPs

3.1.1. Public Education and Outreach

The BMPs for meeting Public Education and Outreach requirements were evaluated and it was found that *physical education materials* and *education materials posted online* were the two most frequent agents for delivering materials, and *education on behavior that may cause stormwater pollution* was the most frequent educational topic (Table 2). This follows guidelines as set forth in NR 216.07, which requires education on "behavior that may cause storm water pollution from sources including automobiles, pets, household hazardous waste, and household practices." While only 27 of 84 indicate that they educate on this topic, it does not mean that other municipalities, which may only discuss agents for delivering materials, are not educating on those topics as well. This ambiguity may represent an opportunity to require more specific language that encourages municipalities to report both the methods in which information is delivered and the topics of those educational efforts.

Table 2. Public education and outreach BMP summary.

Public education and outreach	
Best management practice	Count
Physical educational materials	50
Educational materials posted online	42
Education on behavior that may cause stormwater pollution	27
Seminars, workshops, or classes	17
TV/Radio/Newspaper/Social Media	17
Educate engineers and contractors	11
Education on proper use of lawn and garden fertilizers and pesticides.	12
Stormwater signage or inlet markings	5
Use phone/text/email	3
Other	13

3.1.2. Public Involvement and Participation

For Public Involvement and Participation, it was found that *information posted online* and *educational outreach* were the top actions listed for compliance (Table 3). There was a large degree of overlap between Public Involvement and Participation and Public Education and Outreach actions; and, in fact, some municipalities include the exact same language for both prompts. This could indicate either an opportunity for measures that meet both requirements or a lack of understanding of the difference between Public Education and Outreach and Public Involvement and Participation among municipal stormwater managers. The data in Table 3 may indicate the latter, as the most frequent BMP is *information posted online*, which in itself would not seem to encourage input and participation from the public. However, the remaining actions all appear to fall well within the purpose of the Public Involvement and Participation measure. These indicate a broad range of actions that can be taken, from public meetings to stream clean-up days.

Table 3. Public involvement and participation BMP summary.

Public involvement and participation	

Best management practice	Count
Information posted online	43
Educational approach (i.e., seminars, workshops, classes, presentations, etc.)	36
Meetings open to the public	13
Pollution hotline or other way public can identify problems	10
Resources available to public (i.e., rain barrel giveaway)	9
Stream, park, lake, or other "clean-up day"	7
Information available to public by request	3
Encourage input and participation	2

3.1.3. Illicit Discharge Detection and Elimination

Of the 77 reports that explicitly addressed Illicit Discharge Detection and Elimination, 63 performed inspections, 9 did not specify whether they did or not, and 5 indicated that they did not perform inspections. Of the five that did not perform inspections, explanations included hypotheses that no underground storm sewer pipes (i.e., only above-ground swales and channels) meant no anticipated illicit discharges or outfalls to inspect, or reference to past years where none occurred, justifying a pause in inspections. For those that did perform inspections, the maximum number of outfalls inspected was 730, with an average of 84 and a standard deviation of 175. From these inspections, the maximum number of illicit discharges identified was 9, with an average of 1 and a standard deviation of 2.5.

3.1.4. Construction Site Pollution Control

Requirements for Construction Site Pollution Control are centered around the adoption of ordinances for erosion and sediment control to reduce pollutants from construction site runoff. As such, compliance with this measure is straightforward and comprehensive, as 100% of municipalities reported that they have erosion and/or construction site pollution control standards. Outside of ordinances and enforcement programs, there were generally no other actions listed for compliance with this measure.

3.1.5. Post Construction Stormwater Management

The requirements for Post Construction Stormwater Management are the adoption of an ordinance and procedures for inspecting and enforcing BMP maintenance. The vast majority (97%) of municipalities listed explicit postconstruction stormwater management plans or ordinances in response to this measure. In addition, 78% of municipalities listed a maintenance program for installed stormwater BMPs.

3.1.6. Pollution Prevention

For Pollution Prevention, it was found that street sweeping, inspection, and maintenance of structural BMPs, and management of leaves and grass clippings were the most common practices (Table 4). All three of these actions would appear to require significant resources, including personnel and equipment; however, these are also high-impact practices that influence TSS removal within the models reported in the permit (PV & Associates [16]).

Table 4. Pollution prevention BMP summary.

Pollution prevention	

Best management practices	Count
Street sweeping and cleaning of catch basins	38
Inspection and maintenance of structural BMPs	32
Management of leaves and grass clippings	28
De-icing and road salt guidance	23
Disposal of street sweeping and catch basin cleaning waste	14
Education of municipal or other personnel	12
Hazardous waste collection	8
Planning for municipal garages, storage areas and other municipal facilities	9
Inventory of BMPs	5
Fertilizer program/ordinance	5
Other	9

3.1.7. Other annual report data

In addition to the six minimum control measures, there were other prompts and questions within the permit, some of which are summarized within Table 5. Interestingly, 19 of the municipalities did not prepare their own municipal-wide stormwater management plan and 13 entered into a contract with another entity to perform Public Education and Outreach. This indicates that many municipalities are outsourcing their stormwater permit compliance and may not have the expertise in-house to carry out permit actions. Without in-house expertise, these municipalities may be vulnerable to changes in regulatory oversight that require a programmatic response beyond what a consultant can provide.

Table 5. Summary of other annual report questions.

Question	Yes	No
Has the municipality prepared its own municipal-wide stormwater management plan?	33	19
Is snow hauled away?	28	23
Does the municipality have a maintenance program for installed stormwater BMPs?	38	11
Are adequate revenues being generated to implement your stormwater management program to meet permit requirements?	45	5
Has the municipality entered into a written agreement with another municipality or a contract with another entity to perform one or more of the conditions as provided under section 2.10 of the general permit?	54	13
Has the municipality conducted outfall inspections?	63	5

3.2. Summary of expenditures

Total expenditures for stormwater management varied across municipalities with a minimum, median, and maximum of $1,500, $85,135, and $11,872,580, respectively, and a coefficient of variation (CV) of 3.0. Figure 2 illustrates the expenditures per capita, which shows that there was a median of $7 per capita spent overall on stormwater programs (CV =1.34). As illustrated, there is a large outlier in the self-reported spending that could not be explained by reported BMPs, population, or other socioeconomic data. As such, this municipality is removed from the analysis in the following sections due to its high leverage.

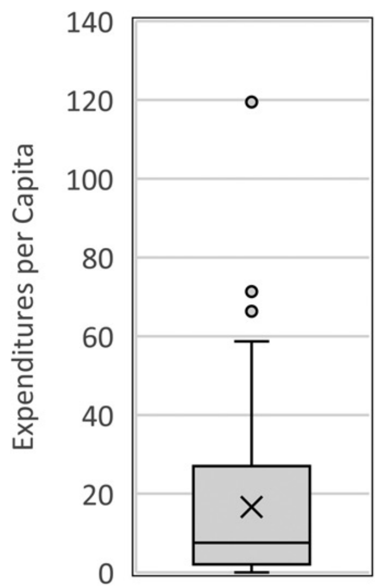

Figure 2. 2015 Expenditures per capita.

The spending by municipalities was broken down across categories by the average expenditures (Figure 3) and the percent of the municipal budget (Figure 4), and in comparing the two figures there are several interesting findings. For example, Public Education and Outreach is the lowest expenditure as an average overall amount (Figure 3); however, as an average percent of the budget it ranks third; and, in fact, there are four municipalities that spend the majority of their funds on Public Education and Outreach (Figure 4). Two of these are Universities and all four have overall budgets of less than $5,000. Furthermore, two of the four spent their entire budget on Public Education and Outreach and the other two split their budget between Public Education and Outreach and Illicit Discharge Detection and Elimination. This indicates that municipalities with small budgets may prioritize Public Education and Outreach spending due to its low-cost and/or high regulatory priority. In addition, it was found that Pollution Prevention is the greatest average expenditure as well as the greatest mean percent of the municipal budget. This indicates that Pollution Prevention may be the greatest economic barrier to achieve compliance to the maximum extent practicable.

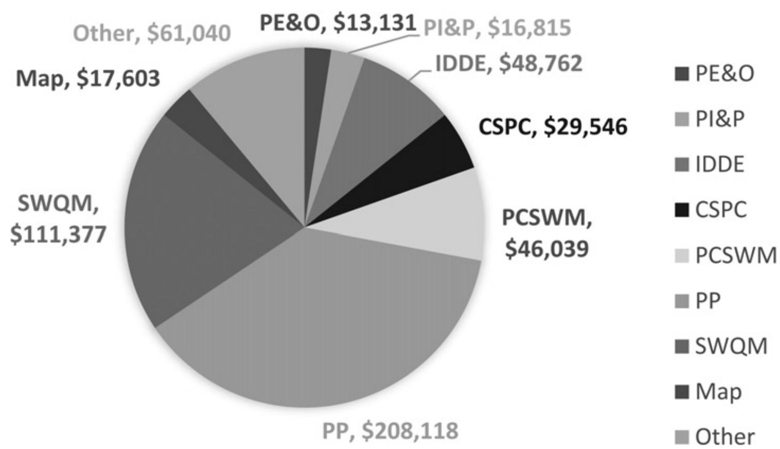

Figure 3. Average amount spent on each category across all municipalities.

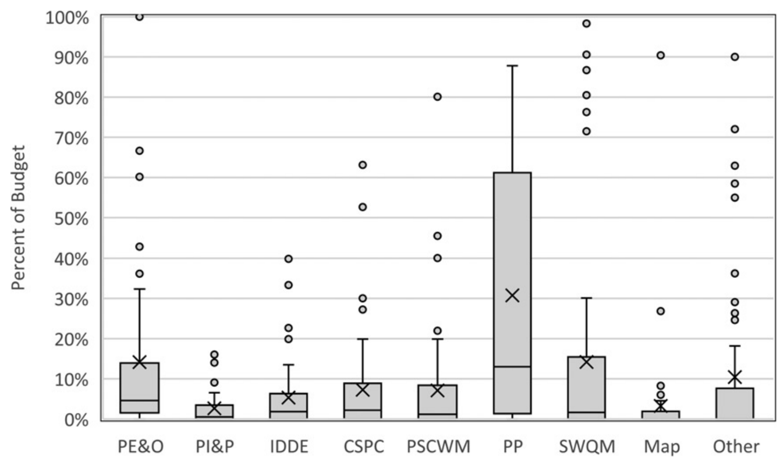

Figure 4. Percent of 2015 budget per category.

There were also high outliers in several categories, as illustrated in Figure 4. For instance, one municipality spent 80% of their budget on Post Construction Stormwater Management, which they indicated was due to significant resources required to revise their postconstruction stormwater management code and stormwater management master plan. Another municipality spent 86% of their budget on their stormwater map, which they indicated was updated as part of a TMDL study. These findings suggest that the long-term planning and scheduling of activities may affect the year-to-year budget of municipalities.

3.3. Statistical analysis of the dataset

Statistical analysis was performed to identify relationships or trends among reported expenditures, socioeconomics, and the adoption of BMPs. Of the six minimum control measures, only Public Education and Outreach, Public Involvement and Participation, Pollution Prevention, and Illicit Discharge Detection and Elimination are required to list specific BMPs used for compliance. The evaluation of these BMPs using one-way analysis of variance, chi-squared and odds ratio is shown in Tables 6 and 7.

Table 6. One-way analysis of variance for public education and outreach, public involvement and participation, and pollution prevention BMPs.

Control measure	Best Management Practice	Predictor	Mean with	Mean without	p > F
PE&O	Stormwater Signage or Inlet Markings	Median value owner-occupied housing	141,700	217,500	0.0355
PE&O	Educate engineers and contractors on how to design, install, and maintain the practices	Number of stormwater practices listed	13	1	0.0024
PE&O	Education on proper use of lawn and garden fertilizers and pesticides	People aged 65 years and over, percent	16.5	14	0.0494
PE&O	Physical Education Materials	Annual expenditures in 2015 for PE&O	1,994	4,492	0.0205
PI&P	Educational approach	Population per square mile	2,439	1,314	0.014
PI&P	Educational approach	People per household	2.41	2.47	0.0182
PI&P	Information posted online	People aged 65 years and over, percent	17.2	14	0.0016
PI&P	Meetings open to the public	% Budget PIP	1	4	0.086
PP	Proper disposal of street sweeping and catch basin cleaning waste	Annual expenditures PP	102,232	19,506	3.71E-05
PP	Routine street sweeping and cleaning of catch basins	Annual expenditures PP	56,497	8,072	0.026

Note: PE&O = Public Education and Outreach; PI&P = Public Involvement and Participation; PP = Pollution Prevention.

Table 7. Chi squared test and odds ratio for public education and outreach, public involvement and participation, and pollution prevention BMPs.

Control measure	Best Management Practice	Predictor	Chi Sq	Prob > Chi Sq	Odds ratio	Lower 95%	Upper 95%
PE&O	Seminars, workshops, or classes	PE&O Physical education materials	5.3	0.021	5.4	1.1	26.0
PP	Hazardous waste collection	Known water quality improvements into receiving waters	7.8	0.005	8.0	1.6	39.1
PP	Hazardous waste collection	PE&O Education on behavior that may cause stormwater pollution	10.8	0.001	7.2	2.0	26.0

PP	Proper disposal of street sweeping and catch basin cleaning waste	Haul away snow	4.8	0.029	5.6	1.1	28.8
PP	Routine inspection and maintenance of municipally owned or operated structural stormwater management facilities	PE&O Educate engineering and contractors on how to design, install and maintain practices	5.8	0.016	9.2	1.1	75.5
IDDE	Conduct outfall inspections	Maintenance program for installed stormwater BMPs	8.1	0.005	7.7	1.7	35.0
IDDE	Conduct outfall inspections	Municipal facility employee training on stormwater PP	6.7	0.010	6.8	1.4	31.6

Note: PE&O = Public Education and Outreach; PP = Pollution Prevention; IDDE = Illicit Discharge Detection and Elimination.

3.3.1. Public Education and Outreach

There are several statistically significant trends in Public Education and Outreach actions. The first significant trends are economic: (1) stormwater signage or inlet markings are found more often in municipalities with a lower median value of owner-occupied housing, and (2) municipalities that utilize physical education materials spend less overall for Public Education and Outreach. This could suggest that stormwater signage or inlet markings and physical education materials represent low-cost solutions for Public Education and Outreach. Another trend is practical: municipalities with more physical stormwater practices installed are more likely to train their personnel on how to maintain such practices.

3.3.2. Public Involvement and Participation

For Public Involvement and Participation, municipalities who left their meetings open to the public spend less as a percentage of their overall budget on Public Involvement and Participation. This could indicate that meetings open to the public is a low-cost method to achieve Public Involvement and Participation compliance. In addition, municipalities with greater population density and people per household were more likely to take an educational approach to Public Involvement and Participation. This could be because municipalities with greater population densities have more constituents and therefore greater potential interest in educational initiatives.

3.3.3. Pollution Prevention

Municipalities who performed street sweeping and cleaning of catchment basins, as well as removal of that waste, spent more overall on Pollution Prevention than those that did not. This suggests that street sweeping and cleaning of catchment basins are high-cost practices for Pollution Prevention. In addition, those municipalities that disposed of street sweeping and catchment basin cleaning waste were also more likely to haul away snow. This could indicate an institutional capacity among municipalities that have equipment and personnel capable of carrying out both activities. Finally, those that disposed of hazardous waste were also more likely to educate on waste disposal (i.e., behavior that may cause stormwater pollution) in their Public Education and Outreach efforts, highlighting a synergy between Pollution Prevention and Public Education and Outreach.

3.3.4. Illicit Discharge Detection and Elimination

It was found that municipalities that do not inspect outfalls are also more likely to not have a municipal maintenance program for installed stormwater BMPs or employee training on stormwater pollution prevention. This could indicate a human capital issue, where municipalities without employees to inspect outfalls also do not have employees to train or perform BMP maintenance. In addition, much of the capital devoted to Illicit Discharge Detection and Elimination is for dry-weather field screening of outfalls (Zielinski and Brown [24]) and, therefore, the total cost of complying with Illicit Discharge Detection and Elimination was evaluated against the number of outfalls inspected to see if there was a correlation, but no discernible trend was detected. The Illicit Discharge Detection and Elimination expenditures had a minimum, median, and maximum of $18, $188, and $32,074 per outfall inspected, respectively.

3.3.5. Developed urbanized area standard

We also evaluated whether any variables correlated with modeled TSS reduction and it was found that population density had a statistically significant impact on the percent reduction reported by the models, as shown in Figure 5a. In this figure, both x and y axis datasets were log-transformed to reduce heteroscedasticity in the residuals and a linear model was fit to the data (R-squared 0.24; t-statistics of the slope 4.0). This trend may indicate that for municipalities with higher population densities, it is more difficult to implement structural BMPs that reduce sediment loads, and/or there is a greater percentage of land disturbance and thus a greater overall postdevelopment TSS load. Therefore, population density may be a constraint for the effective management of TSS as self-reported in the models. However, it should be noted that improvement in self-reported model results does not necessarily mean improvement in actual loads.

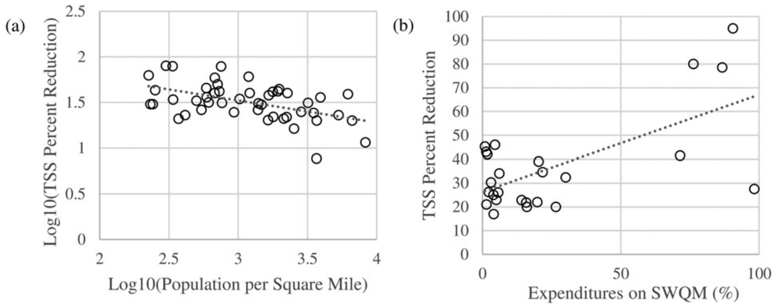

Figure 5. TSS percent reduction as a function of (a) the population per square mile, and (b) the percent of the budget spent on Stormwater Quality Management.

It was also found that the percent reduction in TSS increases as a function of the percent of expenditures spent on Stormwater Quality Management, which includes the implementation and maintenance of municipally owned stormwater facilities and modeling of TSS to demonstrate a 20% reduction. This is verified by a statistically significant linear relationship (t-statistic of 4.01 for the slope) with an R-squared of 0.41 (Figure 5b), but it should be noted that there are a few points with high leverage. While it is not possible to separate implementation and maintenance of BMPs from modeling within the Stormwater Quality Management expenditures, this finding could indicate that (1) municipalities that spend more on modeling are interested in demonstrating improved results from their actions, versus those that know they may not have model improvements to demonstrate, and/or (2) municipalities with more stormwater infrastructure to maintain, and therefore higher Stormwater Quality Management costs, demonstrate greater reduction in TSS due to that infrastructure.

3.3.6. Stormwater utility

Of the 85 municipalities in this study, 19 indicated that they had a stormwater utility and it was found that those with a stormwater utility spend more per capita than municipalities without one (Prob > F 0.004), as illustrated in Figure 6. These results suggest that municipalities with a funding mechanism specific to stormwater management have more funds to allocate towards permit activities. In addition, of the five municipalities that indicated they had insufficient funding to implement their stormwater management program (Table 5), none of them had a stormwater utility.

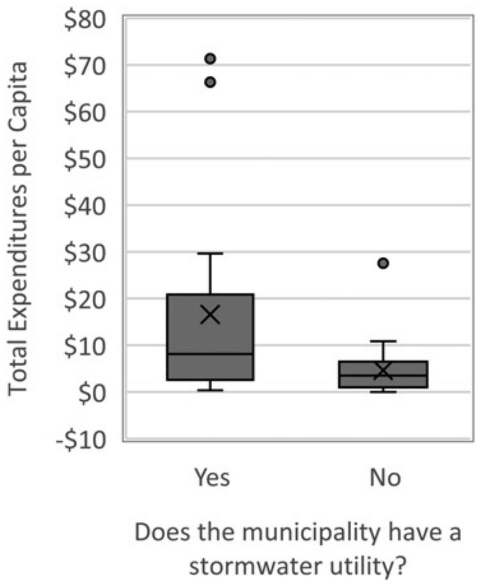

Figure 6. Stormwater expenditures based upon the adoption of a stormwater utility.

3.3.7. Expenditures and socioeconomics

Total expenditures per capita were found to loosely correlate with three socioeconomic variables (Figure 7). The first finding is that expenditures per capita increase as the total retail sales per capita increases (slope t-statistic 2.0). This may suggest that retail sales represent a proxy for the size of the tax base available for stormwater expenditures. Secondly, the expenditures per capita increase as the population per square mile increases (slope t-statistic 3.0). This could indicate that municipalities with greater population density, and therefore denser infrastructure, require greater expenditures to manage that infrastructure. Finally, expenditures per capita decrease as the population change increases (slope t-statistic 2.0). This highlights a challenge and opportunity in stormwater management: if spending is flat then those with decreasing populations will spend more per capita and those with increasing populations will spend less.

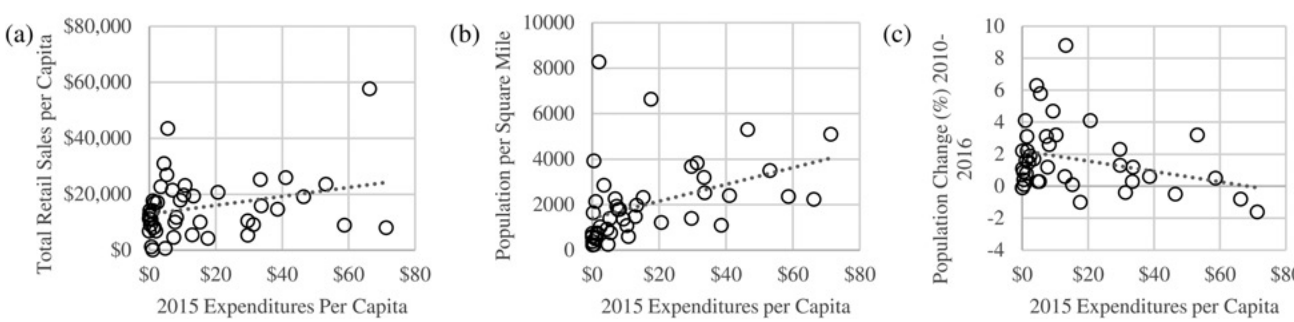

Figure 7. Expenditures per capita versus (a) total retail sales per capita, (b) population per square mile, and (c) population percent change.

3.3.8. Permit compliance mechanisms: contracted or in-house?

One distinguishing factor among municipalities was whether they prepared their own stormwater management plan or had a consultant do it. This categorical variable was evaluated against others within the database, resulting in several findings, as demonstrated in Tables 8 and 9. For example, those that prepared their own stormwater management plan spent more as an overall percent on their Pollution Prevention budget and were more likely to have a stormwater utility to pay for stormwater permit actions. This could indicate that more expensive pollution prevention activities and the implementation of a stormwater utility require in-house expertise to carry out. Conversely, it suggests that municipalities seeking to transition from contracted to in-house permit compliance may need to consider a stormwater utility to raise the capital to do so.

Table 8. One-way analysis of variance for prepared stormwater management plan.

Categorical	Numerical	Mean Yes	Mean No	Prob > F
The municipality prepared its own municipal-wide stormwater management plan	% Budget Pollution Prevention	40	12	0.007
Housing units	87,463	37,129	0.010	
Total merchant wholesaler sales	357,275	1,513,315	0.031	
Total retail sales	365,231	1,277,737	0.034	

Table 9. Chi square test and odds ratio for prepared stormwater management plan.

Variable 1	Variable 2	Chi Sq	Prob > Chi Sq	Odds ratio	Lower 95%	Upper 95%
The municipality prepared its own municipal-wide stormwater management plan	PE&O Education on proper use of lawn and garden fertilizers*	4.849	0.0277	–	–	–
PE&O Seminars, workshops, or classes*	5.961	0.0146	–	–	–	
PI&P Stream, park, or other clean up day*	3.024	0.0821	–	–	–	
PI&P Pollution hotline*	4.657	0.0309				
Stormwater Utility	5.51	0.0189	6.18	1.2	31.7	
Adoption of other ordinances	6.00	0.0143	6.59	1.3	33.7	

Note: PE&O = Public Education and Outreach; PI&P = Public Involvement and Participation. *Action only performed by those that prepared their own stormwater management plan and therefore no odds ratio could be computed.

In addition, there were several Public Education and Outreach and Public Involvement and Participation actions that were only performed by municipalities that prepare their own stormwater management plan (Table 9). This may indicate that these types of actions, such as the organization of a stream clean-up day or the adoption of additional ordinances, require in-house personnel and expertise to organize and implement. This finding supports existing studies that have shown that outsourcing compliance actions distances public stormwater managers from public education activities (Armstrong and Jackson-Smith, [3]). Therefore, municipalities that do not prepare their own stormwater management plan may be constrained by the types of BMPs they can implement, making them less prepared to adapt to changes in regulatory oversight.

3.4. Implications under future stormwater regulations

The results of this study demonstrate a range of actions to meet minimum control measures and highlight opportunities and challenges in NPDES compliance. Opportunities and challenges include recognizing synergies and distinctions between Public Education and Outreach and Pollution Prevention, identification of potentially low-cost BMPs, and the discrepancies between those with and without in-house expertise, among others. These findings are especially important considering the recent passage of the MS4 Remand Rule, which will provide greater permit oversight to regulatory authorities. While specifics of how that oversight will translate into permit compliance are unknown, and may be different for each state, it is possible that permit reports will fall under greater scrutiny. It is therefore important for municipalities to gain an understanding of how others are meeting permit requirements, evaluate how their own actions compare among their contemporaries, and identify where they may have opportunities for improvement.

A significant finding from this study is the distinction between municipalities who have human and equipment capital to carry out permit actions, and those that do not. For example, municipalities that do not prepare their own permit report are unlikely to perform actions that appear to require direct institutional involvement, and there are certain pollution prevention actions more likely to be implemented by municipalities with larger budgets. This may ultimately be a resource issue that can be addressed through taxes, such as a stormwater utility (Kea, Dymond, and Campbell [7]). Adopting a stormwater utility could also have secondary benefits, as private landholders would be incentivized to reduce their fee by implementing BMPs that mitigate stormwater runoff (Valderrama *et al*. [21]). Where a stormwater utility is economically or politically infeasible, such as a lack of willingness to pay for stormwater improvements (Londono Cadavid and Ando [9]), municipalities may need to think of low-cost BMPs (e.g. inlet markings and meetings open to the public), partnerships with external nonprofit and governmental groups to perform certain permit actions (e.g. Fuss [5]), or alternative funding mechanisms, such as a cap-and-trade stormwater allowance market and voluntary offset programs (Parikh *et al*. [14]; Goddard [6]). Each of these solutions can address a lack of resources for stormwater funding, which these results suggest may be a primary reason some municipalities struggle to meet permit requirements.

To this end, while the majority of municipalities in the Southeast Wisconsin region appear to address all minimum control measures in their report, there were a few who did not. For example, some municipalities only allocated resources to Public Education and Outreach and Illicit Discharge Detection and Elimination. These municipalities may, therefore, be subject to more scrutiny and regulatory pressure given the changes in legislation requiring greater oversight; however, determining if and how these municipalities are meeting the maximum extent practicable is subjective and outside of the scope of this project. Consequently, while this case study provides valuable information on municipal BMPs, there are several questions this study cannot answer. For example, how BMPs influence water quality is difficult to know without monitoring – a potential shortcoming of the existing regulations derived from the Clean Water Act (McDonald, Dymond, and Lohani [11]; Subramanian [18]; Markell and Glicksman [10]). In addition, without firm metrics outside of the maximum extent practicable (e.g. Wisconsin's 20% minimum TSS standard), it is difficult to evaluate the impact of one municipality's actions over another. This highlights that while a subjective regulation criterion is valuable for application across diverse jurisdictions, a weakness is the ability to objectively assess the quality of one action versus another, or to know the actual impact on water quality. This challenge remains prevalent for regulators as they seek to develop fair and reasonable criteria that will drive water quality improvements.

In the end, the changes brought forth through to the MS4 Remand Rule will look different depending upon how state regulators choose to exercise their authority and the degree to which existing municipal efforts meet the state defined maximum extent practicable. These municipal efforts will be influenced by the unique physical, economic, social, and governance constraints that impact how municipalities can manage stormwater. For example, this study has demonstrated that those with higher population densities may have a more difficult time obtaining higher TSS removal efficiencies, and those with lower budgets and/or no stormwater utility may not have the capital to invest in certain types of BMPs, such as street sweeping and catchment cleaning. Therefore, the outcomes of this study suggest that state regulators may want to take a flexible and pragmatic approach that considers individual constraints and limitations when defining the maximum extent practicable for each municipality.

While this study was restricted to municipalities in Southeast Wisconsin, it has implications for both national and global stormwater management. At a national level, the MS4 Remand Rule will affect all state-level stormwater governance, and therefore all municpalities in the US may face increased scrutiny of their stormwater management programs. Municipalities can apply these findings to identify low-cost compliance options, compare their own actions and spending to those in this study, or evaluate the value of in-house or contracted management compliance. In addition, socioeconomic findings that are largely independent of climate or geography, such as the difference between municipalities with or without resources or in-house personnel, may generally hold true across the country. At a global level, these findings highlight how municipal governments might respond to top-down regulations that are flexible, such as the maximum extent practicable, rather than a specific numeric criterion. Additionally, it provides insights into the diverse approaches that can be taken to meet specific stormwater management program goals, such as public education and pollution prevention.

4. Conclusions

In summary, the annual MS4 NPDES reports from 85 municipalities in Southeast Wisconsin were cataloged in a database and evaluated against socioeconomic variables. It was found that while there were several common BMPs used to meet the six minimum control measures of the NPDES permit, municipalities largely took a diverse and broad approach to meeting many of their permit requirements – especially with regards to Public Education and Outreach, Public Involvement and Participation, and Pollution Prevention. As such, the following are selected conclusions that can be drawn from this analysis.

- In addressing Public Education and Outreach, municipalities discussed both educational topics and agents to deliver those topics to the public, with many municipalities discussing only one or the other. This may present an area for state-level regulators to be more specific in how municipalities should report Public Education and Outreach actions so that both the topics and agents are reported together.

- While there are actions that could meet more than one control measure, significant overlap between self-reported Public Education and Outreach and Public Involvement and Participation actions indicates that municipal stormwater managers may not grasp differences between the requirements of each measure. Further education or recommendations regarding how actions between these should be delineated and/or can complement one another may improve compliance.
- *Stormwater signage or inlet markings* and *meetings open to the public* may be low-cost approaches to Public Education and Outreach and Public Involvement and Participation, respectively.
- Municipalities that performed street sweeping and cleaning of catchment basins spent more on Pollution Prevention than those that did not, indicating that these may be high-cost practices.
- Pollution Prevention represents the largest expenditure for most municipalities, and, therefore, may be the greatest economic barrier for meeting the maximum extent practicable.
- Synergies can exist between Public Education and Outreach and Pollution Prevention. For example, municipalities that take certain Pollution Prevention actions can use their expertise to develop public education materials on those actions (e.g., disposal of hazardous waste).
- Modeled TSS removal rates decrease as a function of the population density of a municipality. This could be due to greater land disturbances and/or greater difficulty in implementing structural BMPs in dense areas.
- Modeled TSS removal increased as a function of the expenditures spent on Stormwater Quality Management. This could indicate that municipalities who spend more on modeling are interested in demonstrating improved results from their actions, and/or that municipalities with more stormwater infrastructure to maintain, and therefore higher Stormwater Quality Management costs, show more TSS removal due to that infrastructure.
- Construction Site Pollution Control and Post Construction Stormwater Management are perhaps the most straightforward minimum control measures to follow as they only require the adoption of ordinances. As such, nearly every municipality had ordinances in place for these control measures.
- Certain permit activities, such as updating post-construction stormwater management codes or the storm sewer map, may not occur on an annual basis. Therefore, spending dedicated to permit compliance may change on a year-to-year basis depending upon the need to address permit requirements that are revisited on a decadal rather than a yearly timeline.
- Human capital appears to be a distinguishing factor among municipalities as many actions which require in-house expertise (i.e., employee training, inspection of outfalls, etc.) are correlated. In addition, those municipalities that do not develop their own stormwater management plan are unlikely to perform other actions that would appear to require direct municipal efforts, such as the adoption of additional ordinances.
- Municipalities that do not prepare their own stormwater management plans are also more likely to spend less on their Pollution Prevention budget, indicating that they may not have the resources needed to exercise more expensive Pollution Prevention actions that require municipal coordination and personnel.

- Municipalities with a stormwater utility have more funds per capita, on average, than those that do not. This suggests that a stormwater utility is an effective means by which to increase per capita spending for NPDES permit actions.

Overall, the findings demonstrate that there are a broad range of actions and resources that municipalities allocate to meet permit requirements. A challenge for regulators going forward is to determine where in that range the maximum extent practicable should be set for a municipality. Based upon these conclusions, it appears that the maximum extent practicable for stormwater BMPs should be defined individually for each municipality based upon their socioeconomic context. Such an adaptive regulatory approach would consider the existence of a stormwater utility, in-house expertise, and other variables when defining the maximum extent practicable for each municipality. In addition to this challenge, the purpose of the NPDES program is to improve the quality of receiving waters; however, regulations have outpaced the scientific and technological capacity to understand municipal stormwater systems, as there is a lack of data connecting BMPs to actual improvements in water quality (Wagner [22]; Liu *et al*. [8]). Therefore, there is a need for more studies that can build upon these findings to improve our understanding of the interface between regulations, municipal actions, and water quality improvements.

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Footnotes

The US Federal government included municipalities with populations greater than 100,000 underneath the regulatory umbrella of the NPDES program in 1990 (Phase I). This was later modified to also include smaller municipalities in 1999 (Phase II).

The Clean Water Act was passed in 1972, giving the United States Environmental Protection Agency authority to set water quality standards, implement pollution control programs, and regulate pollutant discharges.