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Stormwater utility funding in Phase I MS4s in the Mid-Atlantic United States: implications for compliance and flood resilience

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In the United States, climate change and urbanization are increasing stormwater runoff, flooding, and infrastructure strain, creating pressure for municipalities to adopt sustainable and resilient stormwater management strategies. Addressing these demands requires dedicated funding mechanisms, prompting many municipalities to establish stormwater utilities as a sustainable revenue source. This study examines how Phase I Municipal Separate Storm Sewer System (MS4) municipalities in the Mid-Atlantic region generate and allocate revenue through stormwater utility fees. Financial data for fiscal year 2022 were compiled and analyzed to evaluate spending across major program categories, including operations and maintenance, capital improvements, administration, education, and planning. The results show that operations and maintenance receive the largest share of stormwater utility funding, followed by capital investments, reflecting the expanding needs associated with aging infrastructure, increasing precipitation, and regulatory compliance. The analysis also identifies relationships between expenditure patterns, impervious surface coverage, and levels of urban development, indicating that more densely urbanized areas require higher per-acre investment to maintain adequate system performance. Despite dedicated fees, stormwater utilities continue to report funding gaps that limit their ability to meet long-term infrastructure and resilience needs. These findings suggest that stable revenue mechanisms, periodic rate updates, and proactive planning are essential to strengthen municipal capacity, support regulatory requirements, and enhance resilience under changing hydrologic and urban conditions.

KEYWORDS
climate resilience, municipal stormwater management, stormwater fee, stormwater utilities, sustainable funding

1 Introduction

In the evolving landscape of stormwater management, an increasing number of cities in the United States are adopting stormwater utilities (SWUs). Given the history of regulatory changes, municipalities face challenges in effectively managing stormwater. These challenges include addressing water quality issues and flooding concerns. Recognizing the indispensable role of stable funding in executing comprehensive stormwater management programs, municipalities are turning to SWUs as a reliable financial mechanism. The increase in the implementation of these fees nationwide reflects a growing recognition of the social impacts of robust stormwater management. As the details of stormwater utilities are examined, it is important to understand how these utilities have developed, acknowledge the challenges municipalities face, and emphasize the crucial role of stable funding in sustainable stormwater management initiatives.

The complex responsibilities of stewardship include managing stormwater, which plays a role in addressing ecological and public-safety concerns and in meeting municipal obligations. Municipalities navigate the challenges of safeguarding water quality, mitigating floods, and preserving the vitality of aquatic habitats. However, stormwater management is often constrained by insufficient funding. This examination of stormwater management in the Mid-Atlantic Region (EPA Region 3) will explore the intricacies of funding mechanisms, with a focus on the stormwater utility fee.

According to Treadway and Reese (2000), a stormwater utility is a method for obtaining funds for the stormwater program. Stormwater utilities typically generate most of their revenue through "user" fees. "Use" of the stormwater system is defined as the demand a property places on that system and the stormwater services and facilities provided, which protect the property, downstream properties, and the receiving waters. In the United States, according to Campbell (2025), there are currently 2,147 stormwater utilities, up from 1,807 in 2020, representing an increase of 18.8% in 5 years. A stormwater utility is assessed by a governmental entity, typically a municipality, county, or special regional district in the United States, used to fund the operation, maintenance, and/or capital improvement of stormwater infrastructure (Chalfant, 2018). The fiscal and legal framework governing these U.S. stormwater utilities differs from other international models and shapes how municipalities can use collected revenues. In the United States, stormwater utilities typically operate under a cost-recovery model where revenues must be dedicated to stormwater services. Unlike the self-cost principle used in some international contexts, which restricts fees to covering only actual service costs incurred, U.S. SWUs allow municipalities greater flexibility to build reserves and fund expected operational costs and system modernization. However, most U.S. jurisdictions legally earmark SWU revenues for stormwater-related purposes, and flexibility in revenue allocation varies by state and local ordinance. Most of the time, the fee is based on the amount of impervious surface at the parcel level. Impervious surfaces—streets, roofs, parking lots, and other paved areas—are the primary driver of stormwater runoff volume and pollutant loading in urban watersheds (Brabec et al., 2002). The expansion of impervious surfaces typically directs stormwater runoff directly into receiving waters, disrupting natural infiltration and percolation processes.

Water quality degradation represents a primary environmental challenge in the Chesapeake Bay, the largest estuary in the United States. Pollutants carried by stormwater runoff, including sediments, excess nutrients, and other contaminants, directly impair water quality and threaten aquatic ecosystems. In response to documented impairment, the EPA established the Chesapeake Bay Total Maximum Daily Load (TMDL) as a regulatory mandate requiring jurisdictions to reduce pollutant loads. Concurrently, Municipal Separate Storm Sewer System (MS4) permits issued under the Clean Water Act regulate municipal stormwater discharges and require the implementation of controls to reduce pollutant loads. These interconnected regulatory frameworks, TMDL requirements, and MS4 permits create significant infrastructure and management challenges for municipalities. This study focuses on Phase I MS4 municipalities in the region, which are large jurisdictions (population >100,000) subject to the most stringent regulatory requirements and are therefore positioned at the forefront of stormwater management innovation.

In response to these regulatory mandates, the EPA has increasingly emphasized green infrastructure and Best Management Practices (BMPs) as critical tools for achieving both water quality and water quantity goals. Since the early 2000s, green infrastructure has been recognized as an integrated approach to stormwater management that simultaneously addresses pollutant reduction, runoff volume control, and climate adaptation. Green infrastructure practices enhance water infiltration, reduce runoff, prevent flooding and water quality degradation during intense rainfall events, and support climate adaptation by promoting sustainable urban environments. However, implementing green infrastructure requires sustained financial investment and technical capacity. The 2022 National MS4 Needs Assessment Survey (Water Environment Federation, 2023) found that the primary barriers to updating design standards for changing precipitation patterns and implementing green infrastructure solutions are financial constraints (identified by 45% of respondents as the primary challenge) and insufficient technical knowledge (20% of respondents). These findings indicate that the widespread adoption of green infrastructure solutions depends critically on stable, dedicated funding mechanisms that support both infrastructure investment and the technical expertise required for strategic planning and implementation.

A key challenge for municipalities is achieving MS4 compliance and managing stormwater effectively, given aging infrastructure and changing precipitation patterns. Roy et al. (2008), identified a lack of funding and effective market incentives as one of seven major impediments to sustainable, watershed-scale stormwater management, alongside institutional capacity gaps, fragmented responsibilities, and resistance to change. Without dedicated stormwater funding, municipalities remain confined to reactive maintenance of existing gray infrastructure, managing only what exists to prevent immediate failures. With stable stormwater utility revenue, municipalities can shift toward proactive management that integrates diverse approaches, including asset management optimization, strategic infrastructure planning, and the implementation of practices that treat impervious surfaces, such as green infrastructure and Best Management Practices (BMPs).

As noted above, climate change is altering precipitation patterns, causing historically rare rainfall events to occur more frequently. The return period (the average interval between storms of a given magnitude) is becoming less reliable as a design standard due to changing precipitation patterns and watershed conditions. A case study of Pittsburgh, Pennsylvania (MARISA, 2021) found that current rainfall estimates (Atlas 14) underestimate precipitation for low-frequency storms by approximately 30%, though flooding estimates differ by only 10%. This suggests that urban areas are increasingly vulnerable to flooding under smaller storm events than historical data would predict. However, updating design standards and specifications to account for changing precipitation patterns requires technical expertise and sustained resources. The 2022 National MS4 Needs Assessment Survey (Water Environment Federation, 2023) found that most stormwater programs have not updated design criteria (sizing rules, rainfall depths, storm durations), a gap that directly limits municipalities' capacity to build climate-adaptive infrastructure. Despite these technical and regulatory challenges, the fundamental barrier remains financial: stormwater management has historically been underfunded relative to its importance.

When it comes to water, wastewater, and stormwater management, stormwater is often regarded as the neglected component of this trio (e.g., the "orphan child"). This is mainly because stormwater generally lacks a stable, dedicated funding source. As a result, municipalities often struggle with financing their programs. Findings from Water Environment Federation (2023), indicate that 54% of the respondents said that lack of funding and investments are potential limiting factors to meeting Clean Water Act goals. The survey also showed that 17% of respondents identified funding and financing as the least developed part of their stormwater program, making it the second highest concern in the study after Green Infrastructure/Low Impact Development (18%). These results align with findings from another survey Black and Veatch (2021), where nearly 77% of respondents reported that their funding was inadequate to meet all operations, maintenance (O&M), and capital needs. Together, these surveys underscore that insufficient financial resources remain a pervasive challenge for stormwater programs.

The absence of dedicated revenue for stormwater management causes its funding to compete with essential municipal services like emergency response and education for appropriations from the general fund. It is widely recognized that this competition is not on an even playing field, almost always leaving stormwater management programs with inadequate funding. The conceptual foundation for stormwater utilities rests on recognizing stormwater management as a public service comparable to water supply and wastewater treatment. Debo and Reese (2002), argue that the drainage system should be considered a public system and a public responsibility because drainage systems quickly grow to a scale at which individual property owners lack the technical or financial capacity to manage them. They further note that piecemeal management proves as ineffective as none at all. The growing complexity of stormwater management, encompassing regulatory compliance and public expectations, requires municipalities to develop comprehensive programs that may cost several times current drainage budgets. A stormwater utility addresses this challenge by providing funding that is adequate, stable, equitable, and dedicated solely to the stormwater function (Debo and Reese, 2002). This supports the concept that stormwater utilities, as dedicated funding sources, can be used to support stormwater programs by funding flood-mitigation strategies and water-quality initiatives that will assist municipalities in complying with stormwater regulations while enhancing public safety.

However, while establishing a stormwater utility fee at typical initial rates enables essential programmatic and capital investments for program launch, achieving full-lifecycle cost recovery requires ongoing revenue growth to address deferred maintenance, system expansion, and climate adaptation needs. Municipalities face sustained public opposition to fee implementation and/or increases because stormwater benefits remain largely invisible to residents while fees are highly visible; political constraints frequently delay necessary rate adjustments, creating cycles of underfunding that reinforce public skepticism; and municipalities may lack the technical capacity to plan infrastructure strategically or implement green infrastructure solutions. Stable funding requires not only revenue mechanisms but also sustained municipal commitment to regular rate adjustments, adequate technical capacity, and public communication demonstrating service value.

Understanding the rationale behind this fee as a recommended solution requires delving into the concept of utility. According to the New Jersey Stormwater Utility Resource Center (2022), a stormwater utility is a dedicated funding mechanism to pay for a community's stormwater management program. Much like an electric, gas, drinking water, or sewer utility, the stormwater utility assesses a user fee based on the property owner's usage of the system (i.e., how much stormwater a property generates). Because SWU fees are inherently tied to impervious surface area, the primary driver of runoff volume and pollutant loading, there is a direct relationship between the fee structure and the investments required to convey, treat, and manage runoff to meet regulatory requirements and reduce flood risk. Implementing stormwater utilities effectively requires municipalities to address multiple interconnected dimensions simultaneously: conducting technical assessments of impervious surfaces and rate structures, navigating legal and financial frameworks, managing revenue projections realistically, and engaging communities through sustained communication and public education. The need to balance these technical, legal, and social considerations, while simultaneously overcoming political opposition, building institutional capacity, and demonstrating tangible service value to skeptical residents, creates significant implementation challenges. In this case study, the allocation of stormwater utility revenues will be analyzed for MS4 Phase I municipalities in the Mid-Atlantic Region (EPA Region 3). The study will investigate how expenditures correspond with key factors such as urbanization density, impervious surface coverage, and geographic characteristics. By examining these relationships, the analysis seeks to uncover patterns in municipal prioritization of stormwater investments and to identify how external and contextual factors influence revenue distribution and spending decisions. The results aim to inform policy discussions on sustainable stormwater funding mechanisms.

2 Materials and methods

This study examines stormwater utility (SWU) revenue generation and expenditure patterns for fiscal year 2022, using data from transparency and OpenGov portals and official reports. After collection, the data was filtered to retain only the financial information directly related to SWU expenditures. Tableau was then used for statistical analysis and to visualize the findings. Beyond describing how funds are generated and allocated, this study emphasizes the importance of considering how revenue patterns support the provision of a Level of Service (LOS) consistent with the increasing demands generated by urbanization, climate change, and regulatory pressures, while also shaping municipalities' capacity to strengthen resilience against flooding and improve water quality. These insights are essential for policymaking and long-term planning and also help build public understanding and acceptance of stormwater utilities.

2.1 Study area

The case study focuses on Phase I Municipal Separate Storm Sewer System (MS4) municipalities in the Mid-Atlantic region (EPA Region 3), where 19 of the 25 municipalities have implemented a stormwater utility (SWU). In Maryland, 7 municipalities operate a utility, representing 87.5% of the state's Phase I permits. In Virginia, 9 municipalities have adopted a utility, accounting for 81.8% of permits. Pennsylvania has 2 municipalities, covering 100% of its permits, and the District of Columbia has also established a utility. Of the 19 municipalities identified, this study analyzes 16 with available expenditure data and 17 with available revenue data, representing approximately 84 and 89% of the possible jurisdictions with stormwater utilities in the study area, respectively (see Table 1).

This study investigates how municipalities allocate stormwater utility fee funds, with particular attention to how expenditure patterns align with regulatory compliance, resilience objectives, and the need to sustain the level of service that meets growing demands. The central question, which concerns how municipalities allocate funds generated from stormwater utilities, may seem direct, but securing accurate information proves to be a complex undertaking. Gathering this information requires significant effort, including extensive searches of municipal websites and documents, which often yield only partial results. Yet, because these are public funds, transparency in their use is essential. The objective of this research is to analyze SWU fee expenditures across all MS4 Phase I municipalities in the Mid-Atlantic region and to evaluate how spending patterns correlate with factors such as year of fee implementation, average rainfall, and broader infrastructure and regulatory priorities.

2.2 Data collection

Data accessibility varied notably across states. Among the three analyzed, Maryland stood out for its relatively higher data availability and consistency. This is largely due to structured reporting requirements from the Maryland Department of the Environment (MDE), such as the Financial Assurance Plan (FAP) and the Watershed Implementation Plan (WIP), which require municipalities to submit detailed stormwater expenditure and programmatic data. In contrast, obtaining comparable financial information for Virginia and Pennsylvania required more fragmented, time-intensive searches, often across multiple local sources. Variability in data transparency and reporting standards across states influenced the consistency and granularity of the expenditure data available for analysis.

One jurisdiction in the sample (Chesterfield, VA) exhibits an atypical expenditure profile and was therefore excluded from the quantitative analysis. Chesterfield funds only part of its stormwater program through the utility fee, and in FY2022, it allocated only a small fraction of utility revenue to personnel. Expenditures in that county fluctuate considerably from year to year as projects progress through engineering, construction, and maintenance phases; some years show much higher utility-funded spending than others. It is important to note that, while all other municipalities in the analysis reflect FY2022 expenditure data, Arlington County's data correspond to FY2024, as its SWU was implemented more recently. Given the small sample size, Arlington was included to provide a more complete picture despite the fiscal year difference.

2.3 Expenditure categories

According to Treadway and Reese (2000), stormwater programs typically encompass a range of components, including administration and financial management, operations and maintenance, regulation and enforcement, engineering and planning, capital investment, water quality, public involvement and education, technology, and other related activities. To ensure a proper analysis of revenue allocation, this study merges these elements into six broader expenditure categories: capital programs/improvements, operations and maintenance (O&M), education, grants, administration, and stormwater management planning. These categories were modeled after the reporting structure used by Maryland municipalities, which are the only ones in the region with a consistent and detailed reporting framework. By adopting this structure, the analysis establishes a standardized basis

TABLE 1 Municipalities analyzed, standardized monthly stormwater rates, and total SWU revenue.

Municipalities	Monthly fee		Population	Stormwater utility revenue
	Flat fee	ERU $/1000sf impervious area		
Allentown, PA		$ 3.34	125,944	$ 5,575,338
Anne Arundel County, MD		$ 2.79	590,336	$ 23,988,445
Arlington County, VA		$ 8.96	189,453	$ 18,079,000
Baltimore City, MD		$ 6.62	576,498	$ 28,016,285
Charles County, MD	$ 5.08		168,698	$ 5,915,720
Chesapeake City, VA		$ 5.37	257,269	$ 16,253,822
Chesterfield, VA		$ 0.74	370,688	$ 4,748,956
Hampton, VA		$ 4.87	146,437	$ 11,778,952
Howard County, MD		$ 3.19	334,529	$ 9,866,078
Montgomery County, MD		$ 4.36	1,055,000	$ 42,454,564
Newport News, VA		$ 6.89	184,587	$ 20,747,470
Norfolk, VA		$ 6.78	235,089	$ 22,231,981
Portsmouth, VA		$ 7.59	97,840	$ 11,832,529
Prince George's County, MD		$ 1.40	955,306	$ 21,215,600
Prince William County, VA		$ 1.92	280,813	$ 2,196,000
Virginia Beach, VA		$ 8.37	425,267	$ 45,464,564
Washington D.C.		$ 2.67	712,816	$ 13,560,029

for comparison across all municipalities, even where other states lack equivalent reporting practices. This approach strengthens the consistency of the analysis and yields more meaningful insights into how stormwater utility fees are allocated.

For clarity, each of the six expenditure categories is defined as follows:

Capital Programs/Improvements: Investments in constructing, expanding, or upgrading stormwater infrastructure. These projects aim to increase system capacity and effectiveness and often provide long-term benefits to the community.

Operations and Maintenance (O&M): Day-to-day costs of keeping the stormwater system functional. Typical activities include cleaning storm drains, repairing pipes, maintaining detention ponds, and ensuring facilities operate as intended.

Education: Expenditures that support public outreach and awareness. This includes workshops, community engagement events, informational campaigns, and educational resources for residents, businesses, and stakeholders.

Grants: Funds allocated to support projects or programs, often in partnership with external organizations such as government agencies, nonprofits, or foundations. Grants are frequently directed toward infrastructure upgrades, water quality initiatives, or innovative pilot programs.

Administration: Costs related to program management and oversight. These include billing, legal services, and other general administrative functions necessary for running a stormwater program.

Stormwater Management Planning: Strategic activities focused on long-term system design and regulatory compliance. This category includes watershed planning, monitoring, modeling, and project design to improve stormwater runoff management.

Even though the study outlines six categories for stormwater utility fee funding, municipalities may not allocate funds to all of them. If some municipalities choose not to use stormwater funds for a specific category, it does not imply they are not utilizing other sources to deliver those services. Stormwater utility fee is just one of several financial resources available to municipalities, including bonds, grants, loans, fees, and general funds.

Information was gathered regarding these additional funding sources. The data revealed that nearly 94% of the municipalities analyzed also use grants and/or bonds to supplement their stormwater revenue. In this sample, bonds emerge as the dominant supplemental financing mechanism, frequently linked to capital improvement projects that require substantial upfront investment in infrastructure such as pipe systems, treatment facilities, and detention basin construction. This reliance on revenue bonds reflects the capital intensity of stormwater infrastructure: major projects require financial resources that a single year's utility fee revenue usually cannot provide. In contrast, loans, including state revolving fund (SRF) programs, comprised a smaller share of supplemental financing in the analyzed municipalities, suggesting that revenue bonds are the preferred mechanism for supplementing stormwater utility revenues for this case study. The prevalence of bonds and grants in supplementing utility revenues reflects a fundamental reality: stormwater fees alone are insufficient to cover the full costs of comprehensive stormwater programs. A primary factor contributing to this insufficiency is rate stagnation. As shown in Appendix 1, many municipalities in this sample maintained fixed stormwater fee rates for extended periods despite rising infrastructure costs, inflation, and regulatory demands. When fee rates remain constant while program costs increase, the real purchasing power of utility revenues declines, necessitating supplemental financing to fund the comprehensive stormwater program and sustain adequate service delivery.

The substantial role of alternative financing mechanisms in capital project funding indicates that a comprehensive understanding of stormwater program investment priorities requires consideration of funding sources beyond the utility fee alone, an important area for future research. This analysis focuses on stormwater fee-funded expenditures specifically, recognizing that the true scope of municipal stormwater investment extends beyond stormwater utility fee revenues. Cyre (1987), highlights that while basic stormwater services can be sustained with modest funding, more comprehensive programs, including preventive maintenance and major infrastructure improvements, can cost over $100 per acre and may exceed the revenue generated by typical service charges. These higher costs prompt municipalities to seek funding mechanisms capable of covering such expenditures. In these cases, bonds are particularly well-suited, as they allow local governments to access large sums of capital upfront and repay the debt over time.

A study from Smith (2006), provides further context, noting that stormwater revenue bonds are commonly used after a utility is established. In this model, the stormwater utility fee itself serves as the dedicated revenue stream to demonstrate the ability to repay the bonds. To secure these bonds, municipalities must present a stormwater master plan, a capital improvement plan, and a history of successful revenue collection. While bonds and grants make up the bulk of supplemental revenue, smaller portions also come from general funds or special fees.

2.4 Fee structure and updates

A critical factor shaping the effectiveness of stormwater utilities is whether and how often fee rates are updated. Most municipalities have historically maintained fixed stormwater fee rates for years, which can create funding shortfalls for needed services. Because inflation and regulatory requirements increase stormwater management costs over time, periodic rate increases are necessary to sustain and improve the LOS. This concern is supported by Zhao et al. (2019), who state that when not indexed to inflation, stormwater utility fees lose purchasing power and do not keep pace with the increasing costs of stormwater management. However, raising stormwater fees can be politically challenging, as local officials often hesitate to increase them because of voter resistance and competing priorities. Without periodic rate adjustments, stagnant revenues could leave municipalities unable to fund essential O&M services, capital improvements, or higher service levels.

Appendix 1 summarizes the stormwater fee histories for the studied jurisdictions. Most stormwater utilities maintained their initial fee rates for extended periods, thereby limiting revenue growth. For example, Howard County, MD, set its Watershed Protection Fee in 2013 and did not raise it again until 2024, when it raised it by 155.5%. Likewise, the City of Chesapeake, VA, maintained its residential rate at $7.35 per month for 13 years before increasing it to $11.35 per month. Meanwhile, Allentown, PA, has maintained a very low single-family fee of $1.67 per month since 2018. These divergent approaches show that jurisdictions that delay fee increases are often subject to chronic underfunding. Often, communities lack long-term funding for stormwater programs, making it hard to cover rising maintenance and infrastructure costs.

Before analyzing how municipalities allocate stormwater utility revenues, it is useful to understand the broader fiscal environment in which these decisions occur. The structure and history of local fee rates influence the total revenue available for stormwater programs, shaping what is financially feasible, even if they do not determine specific spending priorities. Examining the evolution of stormwater utility fees across jurisdictions provides insight into how some municipalities have positioned themselves to meet rising infrastructure demands, while others may be constrained by stagnant or outdated rates.

Figure 1 provides a visual overview of how these collected revenues are distributed across major expenditure categories for each municipality, illustrating preliminary differences in investment priorities.

2.5 Analysis methods

This study uses a combined approach of mode and mean analyses to capture both the frequency and magnitude of investment patterns. Mode analysis identifies the most prioritized expenditure categories among municipalities, while mean analysis highlights the average proportion of funds allocated to each category. Together, these metrics provide complementary insights into how stormwater utility fees are operationalized.

Operations and Maintenance (O&M) and Administration emerged as the most frequent primary expenditure categories, each representing the highest level of investment in five municipalities. Among secondary expenditures, Capital Programs were the most commonly reported, the second-largest category in eight jurisdictions.

The mean share of stormwater utility allocations across all municipalities was also calculated to assess overall investment patterns, as shown in Figure 2. On average, O&M accounts for approximately 40% of total expenditure, followed by Capital Programs at 30%, and Administration at 19%. These findings align with the mode-based results, reinforcing that O&M and Capital Programs are not only the most prioritized categories but also receive the largest shares of financial resources overall. The prominence of Capital Programs in this distribution is expected, as explained earlier, because major infrastructure upgrades typically demand substantial upfront investment and thus require a larger share of available funding.

Notably, operations and maintenance and capital investment have also been identified as primary cost drivers in advanced stormwater programs, as emphasized by Treadway and Reese (2000). A similar pattern was observed in a study by Smith (2006), which mentioned stormwater utility expenditures in North Carolina. According to Smith, approximately 44% of stormwater utility funds in the state were allocated to operations and maintenance, while 20% were directed toward capital improvements. Likewise, a 2025 survey by the Southeast Stormwater Association (2025) of 96 responding stormwater utilities (out of 112 identified) found that O&M comprised roughly 34% of stormwater program budgets, with capital improvements accounting for approximately 22%.

The substantial financial investments in O&M and Capital Programs align with vital engineering principles for maintaining functional and sustainable stormwater systems. O&M expenditures typically cover routine system maintenance, ensuring that the infrastructure remains operational and resilient to normal weather. In contrast, Capital Programs involve improvements and expansions that are crucial for enhancing the capacity of stormwater systems, particularly amid urbanization and climate-related stressors, such as increased rainfall.

However, the data from the Black and Veatch (2021) Stormwater Survey reveals that nearly one-third of municipalities reported insufficient funding to meet their O&M and capital needs, highlighting a significant challenge in achieving genuinely sustainable and resilient stormwater infrastructure. This funding shortfall raises concerns about municipalities' ability to plan for and implement necessary

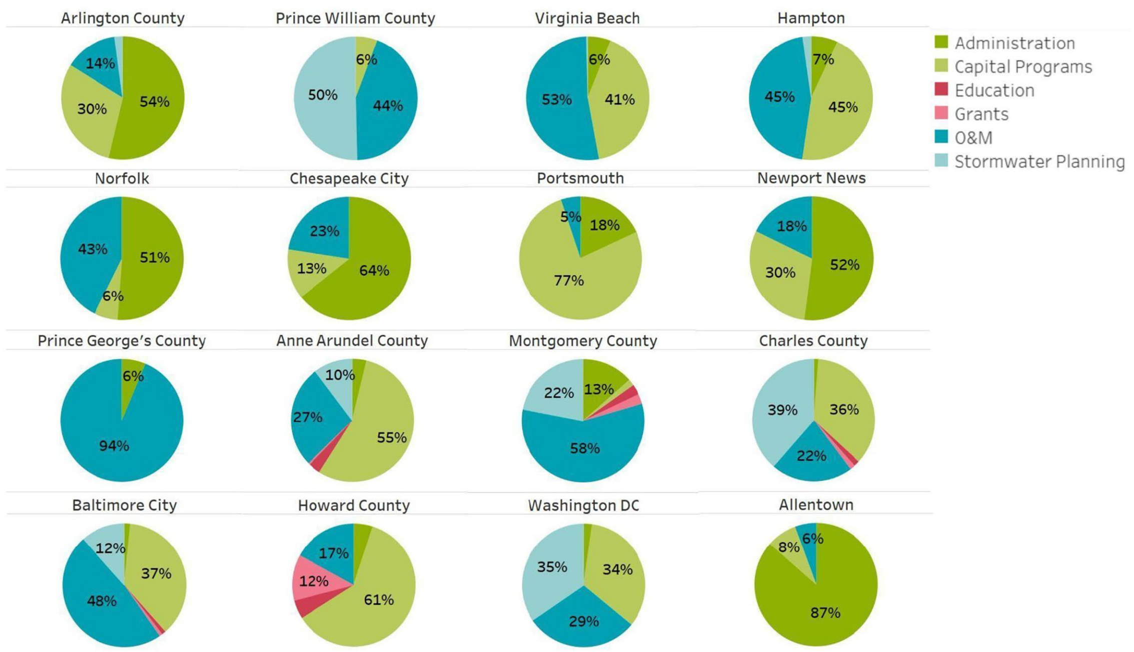

FIGURE 1
Distribution of stormwater utility fee expenditures by category in each municipality.

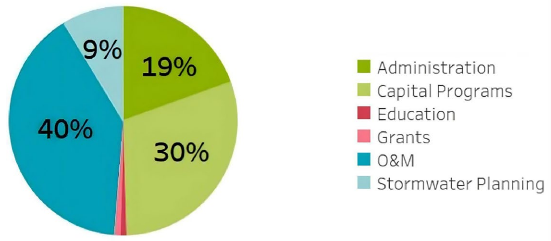

FIGURE 2
Average share of stormwater utility expenditures across municipalities.

infrastructure upgrades that can withstand current and future climate variability. Inadequate capital for upgrades may cause outdated or undersized systems that fail to meet the demands of urban growth and increasingly extreme weather events. Under the NPDES program, all MS4s are required to maintain stormwater systems. From 2018 to 2021, the share of stormwater utilities that developed and implemented maintenance plans increased from 38 to 42%, according to Black and Veatch (2021). The 2025 American Society of Civil Engineers Infrastructure Report Card also notes that more Phase I MS4 respondents reported having a stormwater asset management plan than Phase II MS4s (63% vs. 35%), suggesting that planning and system maintenance remain ongoing challenges (American Society of Civil Engineers, 2025).

It is essential that municipalities not only allocate adequate resources to O&M and capital programs but also integrate long-term planning for system upgrades, wider adoption of green infrastructure, and climate-change adaptation strategies. A robust framework for adaptable and sustainable stormwater systems requires a holistic approach that integrates financial resources with regulatory advancements, public outreach, and synergistic partnerships between different stakeholders. Crucially, municipalities should shift from a reactive, project-by-project posture to a proactive, resilience-focused model: set and monitor clear LOS targets, implement asset management and risk-based prioritization, and use continuous monitoring to anticipate failures and invest in measures that reduce vulnerability. These strategic considerations must also be viewed alongside the cost drivers that shape how municipalities allocate and prioritize stormwater resources.

2.6 Environmental and regulatory context

This underscores the importance of understanding how levels of urbanization influence program costs. Highly urbanized areas tend to have a higher percentage of impervious surfaces, which generate greater runoff and impose greater demand on stormwater infrastructure. In this analysis, the percentage of impervious areas was obtained from multiple sources, including direct communication with municipal staff and Phase I MS4 reports. As a result, these areas often incur higher per-acre stormwater expenditures to manage the volume and intensity of runoff, a relationship reflected in the upward trend in Figure 3 when per-acre spending is compared with impervious surface percentages. This relationship aligns with literature (Environmental Finance Center, 2019) noting that stormwater management costs scale with the amount of runoff generated, which depends directly on impervious cover. The upward trend shown in Figure 3 reflects this pattern: an exponential model explains approximately 61.6% of the variability in per-acre spending ($R^2 = 0.616$, $p = 0.000318$; $n = 16$). Although the association is statistically significant, the modest sample size and potential confounders warrant cautious interpretation.

A related pattern emerges when examining stormwater utility revenue per acre as a function of development intensity. Municipalities with higher percentages of developed land generate more revenue per acre, suggesting that program funding is shaped by the density and scale of the built environment. In this analysis, the percentage of developed areas was derived from the Model My Watershed using the National Land Cover Database (NLCD 2019). This relationship is illustrated in Figure 4, which shows an upward trend between revenue per acre and the percentage of developed areas, reinforcing the connection between urban density and stormwater program resources. Municipal stormwater spending and revenue needs have been shown to scale with impervious area, reflecting the increased infrastructure and maintenance demands in developed regions (King and Hagan, 2011; Environmental Finance Center, 2020). This sample shows an exponential model fits well ($R^2 = 0.785869$, $p < 0.0001$), indicating that revenue per acre increases at an accelerating rate with greater development intensity. These results suggest a robust, non-linear association between development intensity and revenue generation; however, interpretation should remain cautious given the modest sample size ($n = 17$) and the potential for unobserved confounders.

The data presented in Figures 3, 4 underscore that urbanization increases stormwater costs. In denser communities, expanding impervious cover reduces infiltration and sharply increases runoff volumes and peak flows in combination with observed increases in regional precipitation over recent decades. As a result, municipalities must perform more extensive O&M to manage higher flows and prevent system failures. This results in a higher LOS, as utilities commit to more frequent inspections, repairs, and proactive maintenance, which, in turn, increase O&M costs (Environmental Finance Center, 2019). Concurrently, capital improvements are required to increase capacity for the additional stormwater. Thus, per-acre expenditures and revenues climb as development density grows; denser cities invest more per unit area to manage stormwater and protect public safety, property, and water quality (Civica Infrastructure, 2024).

Building on this, literature has emphasized the importance of explicitly defining a minimum and scalable LOS for stormwater programs. For example, the Environmental Finance Center at the University of Maryland developed a Stormwater Level of Service Guide, which outlines tiered frameworks where municipalities may adopt “minimal” service (complaint-based maintenance), “medium” service (scheduled biannual cleaning and inspections), or “high” service (annual inspections, proactive repairs, and expanded green infrastructure) (Environmental Finance Center, 2016). These distinctions highlight that service levels are not static but chosen, and that maintaining even a baseline LOS requires sustained investment. Importantly, higher LOS targets demand greater staffing, operational, and capital resources, reinforcing the need for reliable revenue streams.

Stormwater utilities play a critical role in addressing these challenges by providing a dedicated and stable funding mechanism that can adapt to varying land use intensities. By aligning revenue generation with the extent of impervious coverage or development, utilities ensure that the financial burden is equitably distributed and that adequate resources are available to support long-term infrastructure resilience. This model not only supports the immediate maintenance of stormwater systems but also enables future-focused investments in

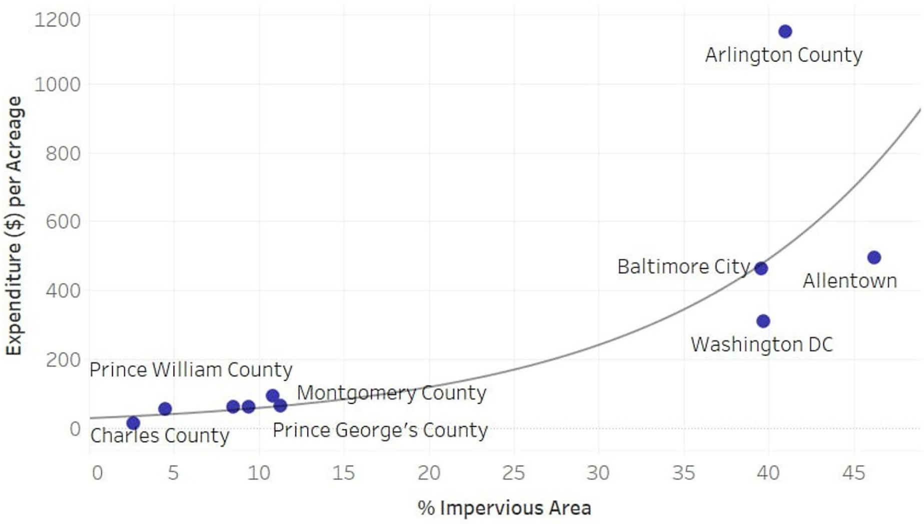

FIGURE 3
Municipal expenditure per acre vs. impervious surface percentage.

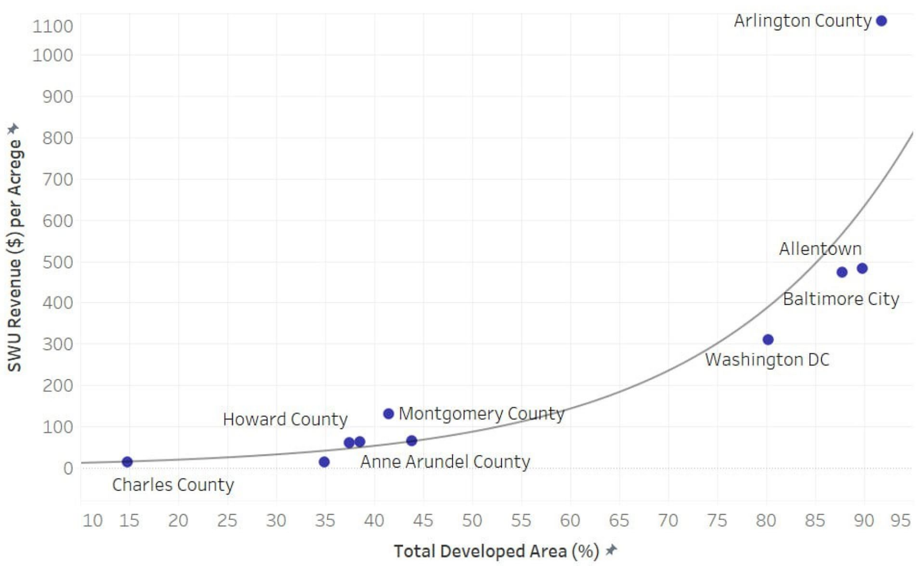

FIGURE 4
Revenue per acre vs. total developed area (%).

green infrastructure, climate adaptation strategies, and system modernization, key pillars for building resilient communities.

3 Results and discussion

3.1 Funding challenges and spatial patterns

Even with stormwater utility fees, municipalities such as Virginia Beach, in this case study, still face substantial challenges in sustaining and improving their stormwater management systems. According to Hood (2024), despite having one of the highest stormwater utility fees per 1,000 square feet of impervious area among the municipalities studied, Virginia Beach projects an annual funding gap of $4–$7 million, risking depletion of its stormwater fund by 2029. To address this, city officials are considering fee increases for single-family homes ranging from $1.80 to $2.71 per month, depending on whether only immediate needs or both current and future needs are incorporated. This example underscores that even well-established funding mechanisms must continually adapt to evolving infrastructure demands and fiscal pressures to ensure long-term resilience.

This study also presents a spatial analysis of municipalities that implement stormwater utility (SWU) fees based on Equivalent Residential Units (ERUs). Each municipality is represented by a circle, with the circle size proportional to the fee charged per 1,000 square feet of impervious surface. Three maps were developed to visualize key environmental and programmatic variables: annual precipitation, increase in annual precipitation over time, and the age of the stormwater utility as shown in Figure 5.

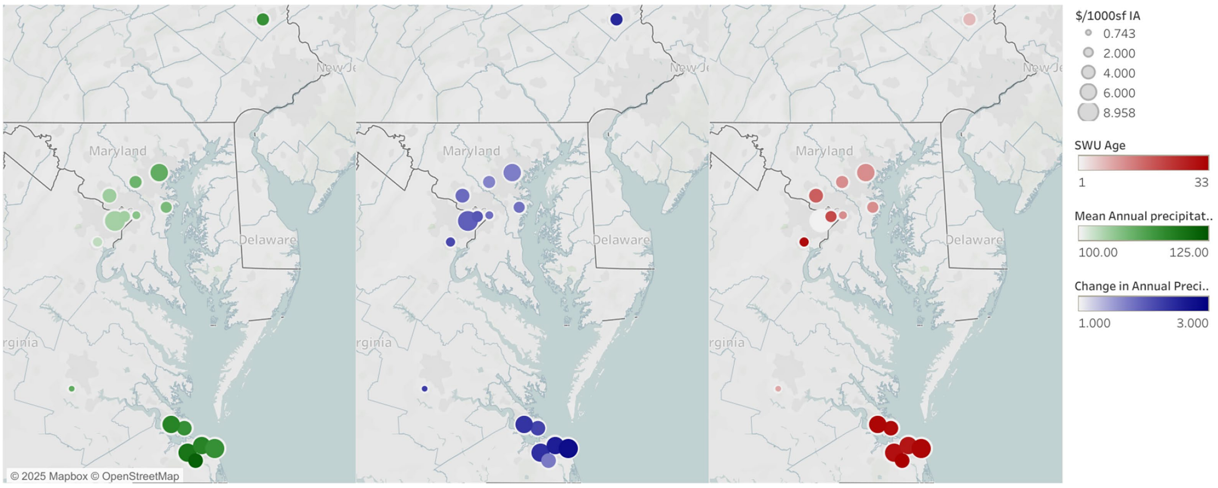

FIGURE 5
Stormwater utility fees and environmental context in ERU-based municipalities.

In the first map, mean annual precipitation is shown, with darker green indicating areas with higher average rainfall. The second map illustrates the change in annual precipitation between 1981 and 2023, with darker blue indicating greater increases over time. The third map presents the age of each stormwater utility program, with darker red colors corresponding to older programs. From the Climate and Hazard Mitigation Planning (CHaMP) Tool, the change in precipitation (in inches per decade from 1981 to 2024) was derived, while mean annual precipitation figures came from Model My Watershed. These datasets provide a reliable basis for evaluating both long-term climatic conditions and more recent precipitation trends relevant to stormwater infrastructure planning.

A clear spatial pattern emerged from the analysis. Municipalities in coastal Virginia exhibited darker red hues, indicating that they had some of the oldest stormwater utilities in the sample. These municipalities also charged higher stormwater fees, as shown by the larger circle sizes. In contrast, Maryland municipalities tended to have more recently established programs, with somewhat lower fee structures. This pattern is partially explained by legislation enacted in Maryland in 2012, which required each of the ten most populous jurisdictions to establish an annual stormwater remediation fee and a local watershed protection and restoration fund. Many Phase I municipalities implemented their fees in 2013 in response. Although the legislation was repealed in 2015, removing the statewide mandate, most of those jurisdictions retained the fee structure, thereby maintaining their stormwater utilities as a long-term strategy.

The environmental context also appeared to play a significant role. Coastal Virginia municipalities not only experienced higher mean annual precipitation but also demonstrated notable increases in precipitation over the last 40 years. Chronic flooding presents a growing threat to these areas; projections from Virginia Department of Conservation and Recreation (2021) in their 2020 Virginia Coastal Resilience Master Plan estimate that between 2020 and 2080, the number of residents living in homes exposed to major coastal flooding will increase by 160%. During the same period, the number of residential, public, and commercial buildings exposed to extreme coastal flooding is projected to increase by nearly 150%, while annualized flood damage is expected to rise by more than 930%, from $550 million to $5.7 billion. Additionally, the length of roadways exposed to chronic coastal flooding is projected to increase by 460%, and approximately 89% of existing tidal wetlands and 38% of existing dunes and beaches could be permanently lost to open water. In response, municipalities in coastal Virginia designed stormwater utilities that address both flood mitigation and water quality, with relatively equal emphasis on both.

3.2 Regulatory drivers: water quality versus flood mitigation

In contrast to coastal Virginia municipalities, where stormwater utilities have been shaped by urgent needs to address both flood mitigation and water quality, stormwater programs in Maryland exhibit a clear and consistent focus on water quality improvements. This emphasis is largely driven by state-level commitments to meet Chesapeake Bay Total Maximum Daily Load (TMDL) requirements, which mandate reductions in pollutant loads such as nitrogen, phosphorus, and sediment. The Stormwater Management—Watershed Protection and Restoration Program (2012), from the House Bill 987 required jurisdictions subject to Phase I MS4 permits to establish stormwater remediation fees to fund activities such as stream and wetland restoration, impervious surface mapping, stormwater system maintenance, and public education. All initiatives are directly tied to improving the quality of runoff entering the Bay. Notably, the legislative fiscal note for House Bill 987 makes no reference to flooding or flood mitigation, underscoring that the primary intent of the program is water quality restoration rather than hydrologic or flood control. This legislative framing, combined with Maryland's Phase II Watershed Implementation Plan strategies, demonstrates that Maryland's stormwater programs are fundamentally oriented toward pollutant reduction and environmental compliance, rather than addressing the increasing risks of chronic flooding observed in neighboring coastal regions. Although the mandatory fee requirement was repealed in 2015 via Senate Bill 863, jurisdictions must still demonstrate adequate funding to meet stormwater management obligations (Edwards, 2015). The effectiveness of this regulatory framework is demonstrated by examining how individual Maryland jurisdictions translate fee revenue into measurable treatment outcomes.

3.3 Linking fee revenue to treatment outcomes

Stormwater utilities structured on impervious-based fees create a direct mechanism linking revenue generation to infrastructure investment. Properties generating runoff contribute proportionally to a dedicated fund based on their impervious surface area; these funds are then allocated to treat that same impervious surface through operational programs and capital projects; and the result is a cumulative portfolio of practices treating impervious surface runoff, requiring ongoing maintenance to sustain treatment performance. Three Maryland MS4 jurisdictions demonstrate this connection, part of a statewide system where nine Phase I jurisdictions have collectively restored 42,964 impervious acres (25% of the total baseline) through $83.7M in annual fee revenue.

Howard County assesses fees based on property type ($40–$225 annually for residential properties) and impervious area ($40 per 500 SF for commercial properties), generating $10.4M in annual revenue. These funds support stream restoration, low impact development (LID) practices, and operational programs. By FY2023, this investment had produced a cumulative portfolio treating 3,223 impervious acres (29% of baseline, the highest among large jurisdictions), with $1.9M allocated annually for O&M.

Montgomery County's stormwater fee, also known as Water Quality Protection Charge ($147 annually per 2,406 SF ERU; residential tiered $48.51–$441) generates $47.5M annually. Revenue funds pond retrofits, stream restorations, voluntary programs (RainScapes, Tree Montgomery), and operational programs. The County has treated 1,190 impervious acres toward its current permit, with $17.4M allocated annually for BMPs maintenance, primarily supported by the stormwater fee (71% of restoration funding).

Anne Arundel County employs an ERU methodology ($98.40 annually per 2,940 SF; residential tiers: $39.36—$196.80 by zoning district), generating $23.0M in revenue and $3.1M from supplemental sources. Funds support infiltration practices, stream restoration, living shorelines, and operational programs, treating 6,792 cumulative impervious acres (27% of baseline). The County allocates $14.9M to capital and $6.8M to O&M, with stormwater fees as the primary funding source. Across all three cases, impervious-based fees serve as the primary revenue mechanism, generating funds proportional to runoff generation that support both new treatment practices and the ongoing operations necessary to maintain cumulative treatment capacity.

While regulatory frameworks served as the primary incentive for the implementation of stormwater utilities, environmental pressures have increasingly reinforced the need for such funding mechanisms. The requirement to comply with Municipal Separate Storm Sewer System (MS4) permits consistently emerged during data collection as a key factor motivating municipalities to establish a stormwater utility. At the same time, intensifying hydrological challenges, including increased rainfall intensity and frequency in the Northeastern United States, are placing stress on aging infrastructure and driving adaptation efforts, which increasingly depend on adequate and sustained financing (Whitehead et al., 2023). Data from Model My Watershed indicated significant variation in mean annual precipitation across municipalities, while the CHaMP Tool revealed measurable increases in total annual precipitation. These trends underscore that stormwater utilities are shaped not only by compliance requirements but also by the practical need to respond to shifting climate conditions that amplify flooding risks and place additional strain on existing systems.

3.4 The evolving regulatory landscape: volume control requirements

This study could also identify that some MS4 permits may also require municipalities to reduce runoff volume, given all the context provided above, as water quality and quantity are intrinsically related. Pennsylvania's 2026–2031 MS4 general permit explicitly requires stormwater volume controls in addition to traditional pollutant-reduction measures. MS4s discharging to certain waters (e.g., Chesapeake Bay tributaries or waters listed as impaired for "Flow Regime Modification") must prepare a Volume Management Plan (VMP). Under this requirement, a permittee must calculate and meet a specified Volume Management Objective (VMO), an annual runoff volume reduction, by a set deadline. Commonwealth of Pennsylvania, Department of Environmental Protection, Bureau of Clean Water (2025) explains that this focus on runoff volume is integral to water quality. In other words, Pennsylvania's MS4 permit explicitly embeds water quantity control alongside water quality controls.

Likewise, Washington, D.C.'s MS4 permit includes strict stormwater retention requirements. Their NPDES Permit No. DC0000221 tells that the 2023–2028 DC MS4 permit mandates that all new and redeveloped projects (≥5,000 ft^2) implement stormwater controls to achieve on-site retention of 1.2 inches of runoff from a 24-h storm (72-h dry period). The permit directs the District to "mimic pre-development hydrology" by integrating retention measures (e.g., infiltration, evapotranspiration, rainwater harvesting) at the site, neighborhood, and watershed levels. It also maintains a Stormwater Retention Credit (SRC) off-site mitigation program to compensate for any portion of the retention requirement not met on-site. Washington, D.C.'s MS4 permit pairs traditional water quality BMPs with a numeric runoff-retention standard, a core runoff-volume control requirement that enforces water quantity reductions.

In Maryland, Environmental Site Design (ESD) is a regulatory requirement established under the Maryland Stormwater Management Act of 2007. The Maryland Stormwater Design Manual mandates the use of low-impact development (LID) techniques for new development and redevelopment in MS4 areas to manage runoff from impervious surfaces. These practices must direct stormwater to on-site infiltration, evapotranspiration, or retention features, functioning as a volume-control strategy. While the regulations do not prescribe a specific infiltration volume, they require that post-development runoff does not exceed pre-development conditions. Maryland's approach exemplifies a broader trend in stormwater governance that treats runoff volume reduction as integral to water quality protection (Maryland Department of the Environment, 2008).

Another example is Milwaukee, which stands out for its bold regional commitment to stormwater management, anchored by the Milwaukee Metropolitan Sewerage District's (MMSD) 2035 Vision of zero sanitary sewer overflows and zero basement backups, a goal that sets the city apart nationally. To support this vision, Milwaukee requires new developments to retain the first 0.5 inches of rainfall on-site, a volume-based control standard aimed at reducing runoff and improving water quality. As outlined in Chapter 120 of the city's (Storm Water Management Regulations, 2018), this requirement can be met through infiltration, evapotranspiration, or rainwater harvesting, with green infrastructure playing a central role. By embedding volume retention into its regulatory structure and aligning with long-term infrastructure goals, Milwaukee's MS4 strategy demonstrates how cities can lead with innovation and resilience in adapting to evolving stormwater challenges.

Such mandates illustrate a broader regulatory shift in stormwater governance: controlling runoff volume is no longer treated as secondary to pollutant removal but as a coequal requirement for protecting water quality. By embedding volume-based standards in permits, regulators are reframing compliance expectations around hydrologic restoration rather than pollutant treatment alone. This evolution compels municipalities to expand investments in infrastructure that detains and infiltrates stormwater, reinforcing the urgent need for stable, dedicated funding streams to sustain compliance with these more demanding requirements.

3.5 Implications for funding stability and municipal resilience

The findings from this analysis underscore the critical importance of establishing dedicated and stable revenue sources for the effective management and long-term sustainability of stormwater utilities. The data demonstrates that municipalities, particularly in Maryland and coastal Virginia, have developed stormwater programs in response to specific environmental pressures and regulatory frameworks. However, adequately addressing these challenges, ranging from flood mitigation to water quality improvement, depends heavily on reliable funding mechanisms. The variation in fee structures and the reliance on state-level mandates illustrate the diverse approaches municipalities have taken to secure funding for stormwater infrastructure. Importantly, the increasing frequency and intensity of precipitation events, along with the projected rise in flood risks, highlight the need for municipalities to maintain robust financial resources to adapt and maintain infrastructure. A stable source of revenue is essential not only to meet regulatory obligations but also to ensure that municipalities can implement, improve, and sustain resilient stormwater systems that can effectively respond to the evolving impacts of climate change and urban development.

Considering these findings, municipalities need not only stable funding but also the capacity to monitor performance and strengthen their stormwater utilities over time. Financial resources alone are insufficient if programs cannot assess effectiveness, identify implementation gaps, and strategically prioritize improvements. Building these capacities ensures that stormwater systems remain adaptive, accountable, and resilient in the face of regulatory demands and climate pressures.

4 Conclusion

This study underscores the critical role of stormwater utilities in securing sustainable funding for effective stormwater management in Phase I MS4 municipalities across the Mid-Atlantic region. The analysis suggests that, although environmental and regulatory pressures vary across jurisdictions, stable and dedicated revenue streams enable municipalities to prioritize essential expenditures in operations, maintenance, and capital improvements. It also indicates that patterns of stormwater utility spending are shaped by multiple factors, including levels of urbanization, shifting precipitation trends, regulatory frameworks, and climate-related demands.

During data collection, it was observed that the primary driver for the initial implementation of stormwater utilities was compliance with MS4 permit requirements. Although motivations have since evolved, with some jurisdictions now emphasizing flood risk and resilience, the establishment of fees was entirely driven by regulatory mandates. These findings highlight the pivotal role of environmental regulation in shaping local stormwater funding mechanisms.

As municipalities continue to confront escalating demands associated with urban growth, regulatory obligations, and climate variability, the importance of understanding expenditure patterns, anticipating future needs, and maintaining resilient and adaptable infrastructure becomes increasingly clear. By aligning technical, financial, and community-focused approaches, stormwater utilities can address current challenges while laying the foundation for sustainable, climate-resilient communities.

The initial objective of this study was to identify trends and develop models to estimate the allocation of stormwater utility revenue to specific expenditure categories. However, this approach was reconsidered after it became apparent that, even where stormwater utilities are established, most municipalities face persistent budget constraints that limit their ability to fully fund their programs. While this case study was being developed, a parallel project involving over 120 interviews with stormwater program managers, directors of public works, engineers, and consulting firms was conducted. Among the 47 municipalities with an implemented stormwater fee, approximately 83% reported that their stormwater programs remain underfunded. Given this consistent underfunding across jurisdictions, publishing predictive revenue-allocation models could risk generating misleading conclusions or unrealistic expectations. Instead, the analysis emphasizes observed expenditure patterns, providing grounded and practical insights without relying on potentially unreliable predictive tools.

Moreover, stormwater utilities are increasingly critical in helping jurisdictions address a growing funding gap for operations and maintenance. The scale of the challenge is stark: Howard County's MS4 reporting indicates 2,453 BMPs in 2007 and 15,544 BMPs in 2024 (Howard County Department of Public Works, Stormwater Management Division, 2008, 2024), representing more than a sixfold increase over 18 years. This rapid expansion, driven in part by broader adoption of green infrastructure practices such as rain gardens, bioswales, and permeable pavements, highlights both the hydrologic and environmental benefits of these approaches and their comparatively specialized and frequent upkeep needs relative to conventional gray infrastructure.

As this green infrastructure portfolio ages, the central challenge becomes clear: jurisdictions are rapidly expanding Best Management Practices implementation, which brings real benefits for infiltration, water quality, and resilience, yet many programs already struggle with limited budgets. But what happens when today's growing inventory of BMPs reaches the end of its design life? Should municipalities retrofit, replace, or decommission them? Who will be responsible for escalating maintenance and renewal costs? These realities highlight the critical importance of stable, dedicated stormwater utility revenues to sustain condition assessment, routine O&M, and lifecycle renewal, ensuring that programs remain compliant, functional, and resilient.

These findings align with fundamental principles of stormwater infrastructure management. Debo and Reese (2002) observe that drainage systems do not self-improve over time, they deteriorate, and often the true extent of decay becomes apparent only when a flood exceeds design capacity. Without stable, dedicated funding, stormwater managers cannot plan beyond minimal caretaker programs; they remain confined to reactive, complaint-driven operations rather than managing proactive maintenance or climate adaptation initiatives. As this study demonstrates, when adequate financing is available through stormwater utilities, municipalities can transition from reactive management to proactive, resilience-focused planning.

Ultimately, the findings of this study highlight the growing importance of Level of Service (LOS) as a guiding principle in stormwater management. As infrastructure ages, urban density increases, and precipitation patterns intensify, expectations placed on municipal stormwater systems continue to expand. Stormwater utilities play a pivotal role in enabling the transition from reactive program management to proactive, resilient system planning. Framing LOS as a benchmark that can inform funding decisions and long-term planning supports accountability and strategic investment. Incorporating considerations of equity, effective utility governance, and climate-adaptive strategies further enhances the capacity of municipalities to build resilient communities in the face of ongoing environmental and operational challenges.

Data availability statement

The data used in this study were compiled from two sources: (1) publicly available municipal and state reports and websites, and (2) information obtained directly from municipal staff through email communication and phone calls. All publicly available data can be accessed through the respective municipal or state websites as described in the manuscript. However, the specific datasets and documents provided through direct correspondence cannot be made publicly available. These materials do not contain personal or identifiable human subject information, but they are considered internal administrative documents. All data necessary to support the analyses, results, and conclusions of this study are fully presented within the article.

Ethics statement

Written informed consent for participation was not required from the participants in accordance with the national legislation and institutional requirements.

Author contributions

AP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. JH: Conceptualization, Formal analysis, Investigation, Project administration, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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