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Toward Net Zero CSO: Designing a Real-Time Metrics Dashboard for Gowanus

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Abstract: An equity-oriented monitoring framework is introduced to track Combined Sewer Overflows (CSOs) in Brooklyn's Gowanus Canal, where legacy infrastructure and redevelopment pressures converge to shape flood and pollution dynamics. Unlike existing stormwater dashboards, this framework unites permit-level regulatory data with spatial equity analytics to enhance transparency and environmental justice. The CSO Metrics Dashboard integrates regulatory data, rainfall observations, and calibrated simulations using the U.S. Environmental Protection Agency's Storm Water Management Model (EPA SWMM) to evaluate stormwater system performance under New York City's Unified Stormwater Rule (USWR). Grounded in the Gowanus Points of Agreement, the framework operationalizes transparency and accountability through open data publication, participatory review, and geospatial visualization. It synthesizes Site Connection Proposal (SCP) permits, State Pollutant Discharge Elimination System (SPDES) reports, and SWMM outputs to quantify overflow behavior and clarify infrastructure accountability across the sewershed. Linking environmental data with demographic and spatial equity indicators at the census block-group scale, the dashboard identifies disparities in exposure and resilience among neighborhoods. Preliminary model validation indicates event classification accuracy within ±10% of SPDES baselines. Ultimately, the framework advances participatory oversight and adaptive stormwater management, offering a transferable model for cities seeking transparent, data-driven, and equitable governance to achieve Net-Zero CSO outcomes.

Keywords: Combined Sewer Overflow (CSO), Unified Stormwater Rule (USWR), Environmental Justice, Urban Data Governance, GeoAI, Equitable Infrastructure, Climate Resilience, Gowanus Canal

Introduction

Across the United States, cities continue to struggle with combined sewer systems that release untreated wastewater into local waterways during heavy rainstorms. New York City is no exception. Combined Sewer Overflows (CSOs) remain a significant threat to urban water quality and public health. Aging infrastructure, rising impervious surfaces, and more intense rainfall have overwhelmed traditional sewer systems (Botturi et al., 2020). The Gowanus Canal in Brooklyn highlights this problem. Even light rain can cause overflows that discharge untreated waste into a sensitive tidal waterway, already damaged by over a century of industrial pollution and poor land-use decisions.

In 2021, New York City adopted the Unified Stormwater Rule (USWR) as part of the Gowanus rezoning agreement. The regulation aims to guide the neighborhood's transition from industrial to mixed-use residential development while improving stormwater management standards. It extends stormwater requirements to all new projects connected to the city's combined sewer system and requires monitoring of both stormwater and sanitary discharges. The USWR also establishes a framework for long-term infrastructure investments to reduce flooding, enhance water quality, and boost climate resilience.

Meanwhile, the Gowanus Oversight Task Force (GOTF), a coalition of community members, advocates, and agency representatives, developed a community-driven plan to achieve Net Zero CSO. This plan emphasizes green infrastructure, data transparency, and participatory oversight to promote fair water management. However, regulation and advocacy alone cannot fully close the accountability gap. Effective CSO governance must be real-time, transparent, and equity-focused, supported by tools that the public can easily understand and trust. Currently, no single platform integrates data from Site Connection Proposal (SCP) permits, State Pollutant Discharge Elimination System (SPDES) reports, and hydrologic modeling outputs into a unified, publicly accessible system. This lack of integration keeps data isolated and limits the ability of frontline communities—those most affected by flooding and pollution—to actively participate in decision-making processes designed to protect them (Pearsall & Pierce, 2010; Anguelovski et al., 2018).

To address this gap, this paper introduces the CSO Metrics Dashboard, an equity-focused conceptual framework and digital prototype designed to make stormwater data visible, understandable, and actionable. The dashboard combines technical and social aspects of stormwater management by visualizing compliance, monitoring green infrastructure outcomes, and linking system performance to environmental justice indicators. Built on participatory principles, the model redefines how hydrologic and regulatory data can be used to develop public oversight tools. In doing so, it increases accountability and provides a scalable framework for transparent, fair stormwater management in cities striving for Net Zero CSO goals.

Literature Review

Modeling, Monitoring, and Governance of Combined Sewer Overflows

Ecological and Public Health Impacts of CSOs

Combined Sewer Overflows (CSOs) are a major source of urban water pollution in aging city infrastructure. During rainstorms, these systems release mixed untreated wastewater and stormwater into nearby waterways, carrying pathogens, nutrients, heavy metals, pharmaceuticals, and microplastics that threaten both ecological and human health (EPA, 2020; Gasperi et al., 2008; Rimer et al., 2023). These discharges lead to eutrophication, hypoxia, and long-term losses in aquatic biodiversity (Carpenter et al., 1998; Diaz & Rosenberg, 2008). As climate change increases rainfall variability and urbanization expands impervious surfaces, the pressure on combined sewer systems continues to grow (Botturi et al., 2020). The environmental and public health burdens of CSOs are not evenly spread across urban populations. Low-income communities and communities of color often experience greater exposure to polluted waterways, limited access to clean and safe recreational areas, and higher risks of waterborne diseases (Mohai et al., 2009; Maantay, 2002; Anguelovski et al., 2018). These disparities reveal larger patterns of environmental injustice and spatial segregation in urban infrastructure planning. To promote fairness in CSO governance, frameworks must combine hydrologic modeling with spatial and demographic analyses to pinpoint where pollution, flooding, and underinvestment overlap.

Data-driven approaches that link monitoring, modeling, and environmental justice are increasingly regarded as essential for the adaptive management of urban water systems (Bandara et al., 2025; Si et al., 2025). By integrating real-time sensing with spatial analysis, cities can better identify vulnerable subcatchments, target green infrastructure efforts, and evaluate the distributional impacts of regulatory policies. This systems approach considers

CSO management not only as an engineering challenge but also as a matter of social equity and transparency in governance.

Modeling and RTC Solutions

Traditional infrastructure responses, such as enlarging pipes, building additional tunnels, or expanding treatment plants, are capital-intensive and often insufficient to keep up with the increasing intensity and frequency of rainfall events driven by climate change. In response, digital modeling and Real-Time Control (RTC) systems have emerged as versatile, cost-effective strategies for managing urban stormwater. RTC technologies combine sensor networks, telemetry, and predictive algorithms to dynamically optimize sewer operations, automatically adjusting gates, pumps, and storage volumes in real time to prevent overflow events. Tools like the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) and Xylem's Vue platform now enable continuous monitoring, scenario simulation, and predictive control to support data-driven decision-making (EPA, 2022; Xylem, 2022). By integrating hydraulic modeling with supervisory control and data acquisition (SCADA) systems, these platforms allow utilities to test adaptive responses before, during, and after storm events, improving both system reliability and environmental compliance.

Real-world applications demonstrate tangible benefits. In Richmond, Virginia, deploying RTC and predictive analytics reduced annual combined sewer overflow (CSO) volumes by more than 182 million gallons. Similarly, Buffalo, New York, saved roughly \$145 million in capital costs by using RTC technologies and targeted green infrastructure retrofits (Xylem, 2022). Similar results in South Bend, Indiana, and Cincinnati, Ohio, highlight the scalability of data-driven optimization in older combined sewer networks (Rimer et al., 2023). Together, these initiatives show how modeling and RTC systems enhance operational efficiency, decrease overflow frequency, and extend the lifespan of existing infrastructure, supporting the shift toward more sustainable and resilient stormwater management. In the Gowanus area, such digital integration isn't just a technical innovation but also a governance opportunity: it enables transparent performance monitoring, equitable resource distribution, and community-focused oversight of CSO mitigation efforts.

Green Infrastructure and Blue-Green Strategies

Blue-Green Infrastructure (BGI), including bioswales, green roofs, permeable pavements, and constructed wetlands, has gained recognition as a decentralized addition to traditional stormwater systems. By capturing and filtering runoff at its source, BGI reduces the volume of water entering combined sewers, improves infiltration, mitigates urban heat island effects, and supports habitat connectivity. These nature-based strategies enhance water quality and strengthen climate and flood resilience through the integration of ecological processes into the built environment (Nature Sustainability, 2024; IWA Blue-Green Systems, 2023). Constructed wetlands offer a cost-effective, low-maintenance way to treat stormwater while restoring essential ecosystem functions.

Evidence supports the many benefits of blue-green infrastructure. In Italy, studies have shown benefit-to-cost ratios ranging from 4 to 10, driven by improvements in water quality, increased ecosystem services, and stronger community well-being (Liquete et al., 2016; Rizzo et al., 2018). In Bologna, installing constructed wetland filtration systems significantly cut nutrient loads while providing measurable ecological and social advantages, highlighting the effectiveness of nature-based solutions in urban water management. Similarly, Vienna's redesign of the Danube Canal offers a strong example: through eco-engineered filtration zones and riparian habitat improvements, the project enhanced water quality and boosted recreation, including designated urban bathing areas, while reconnecting residents to the waterway (Penz et al., 2024). Collectively, these

European efforts show how environmental restoration, fair public access, and data-driven water quality management can work together to turn degraded urban waterways into inclusive, resilient, and ecologically functional spaces, lessons highly relevant to ongoing work in Gowanus and other post-industrial urban areas.

When design, monitoring, and community involvement are integrated from the beginning, blue-green infrastructure can provide measurable ecological improvements along with social benefits. However, applying these successes to New York City faces challenges such as regulatory complexity, legacy infrastructure, and socio-spatial inequalities. In this context, the Gowanus Canal acts as a vital testing ground for adapting these principles, connecting environmental restoration with equitable governance through transparent, real-time monitoring systems like the proposed CSO Metrics Dashboard.

Metrics, Transparency, and Participatory Governance

Despite major advances in digital modeling and infrastructure upgrades, most cities still lack integrated platforms that connect permit data, real-time monitoring, and hydrologic modeling. This ongoing fragmentation hinders cross-agency coordination, limits adaptive management, and erodes public trust. Scholars highlight that metrics-based and participatory governance frameworks are essential for transforming technical data into accountability tools accessible to both regulators and residents (van Ginkel et al., 2018; Kale et al., 2024). South Bend, Indiana, offers a strong example. Its CSO monitoring network, consisting of 165 distributed sensors, achieved an 80% reduction in overflow volumes and saved an estimated $400 million in capital costs. At the same time, E. coli levels in local waterways dropped by more than half, and civic trust increased as residents accessed performance data through an open, real-time dashboard (Xylem, 2024; Environmental Resilience Institute [ERI], 2024). Similar initiatives in Cincinnati and Buffalo helped revise their Long-Term Control Plans, aligning infrastructure investments with measurable community outcomes. These examples demonstrate that transparent, data-driven systems can shift stormwater governance from a strict compliance model to a performance-based approach that promotes environmental justice and equity. By making infrastructure performance understandable to the public, these systems democratize access to information, foster civic co-ownership of sustainability goals, and bolster the legitimacy of urban environmental decision-making. In this evolving landscape, the Gowanus CSO Metrics Dashboard seeks to extend these principles, integrating transparency, accountability, and participatory governance directly into stormwater management's digital infrastructure.

Beyond New York City, the CSO Metrics Dashboard demonstrates a replicable model for cities worldwide confronting legacy infrastructure, stormwater pollution, and data fragmentation. Comparable challenges exist in cities such as London, Copenhagen, Singapore, and São Paulo, where integrated water management frameworks seek to balance technological innovation with social equity. In Copenhagen, for instance, the Cloudburst Management Plan links hydrologic modeling and community engagement to reduce urban flood risk, while Singapore's Smart Water Grid employs real-time data analytics to manage stormwater and potable water resources simultaneously. The Gowanus framework contributes to this global conversation by illustrating how open data, participatory oversight, and equity metrics can be combined into a single transparent platform. It provides a flexible model for data justice and climate adaptation that can inform other urban watersheds striving to meet the UN Sustainable Development Goals (SDG 6.3, 11.3, and 13.1).

Real-Time Environmental Monitoring and IoT-Enabled Stormwater Systems

Building on advances in modeling and participatory governance, the next frontier in stormwater management involves integrating Internet of Things (IoT) sensing with smart Supervisory Control and Data Acquisition (SCADA) systems. These technologies have shifted urban water management from periodic reporting to continuous, event-driven control and verification. While proprietary systems like Xylem Vue remain common, many municipalities now prefer open-source or hybrid sensor networks to cut costs, boost transparency, and enhance interoperability among agencies. These distributed networks provide high-resolution data on rainfall, flow, and pollutant loads, which are useful for predictive maintenance, adaptive control, and early warning during storm events.

In Detroit, sensors installed at fourteen green infrastructure (GI) sites monitor stormwater drawdown in real time, revealing significant variation among parcels and highlighting the need for site-specific performance data to inform investment and design decisions (Mason et al., 2023). The open-source PyStorms platform (Rimer et al., 2021) similarly enables researchers to test real-time control algorithms with both synthetic and real datasets, providing a virtual environment for innovation and scenario exploration.

Similar progress is seen worldwide. In Melbourne, LoRaWAN-connected ultrasonic and pressure sensors continuously send data to a cloud dashboard that detects blockages and assists flood risk planning (City of Melbourne, 2024). In the U.S., Philadelphia's Green City, Clean Waters initiative and Boston's Charles River Watershed Report Card show how IoT dashboards can combine environmental data with civic engagement, making hydrological information accessible and promoting fairness in urban water governance.

The lessons learned from these projects directly influence the design of the Gowanus CSO Metrics Dashboard. The platform combines open architecture, real-time data, and community observations to support participatory oversight and local accountability. As explained in the Methods Section, its modular design encourages citizen science through partnerships with networks like CoCoRaHS and aligns with New York City's Unified Stormwater Rule. In this way, it demonstrates that technological innovation should serve both environmental performance and environmental justice, turning monitoring infrastructure into a tool for civic trust and equitable governance.

Synthesis and Gap Identification

Although the literature on intelligent water systems, digital twins, and environmental equity continues to grow, few frameworks explicitly connect real-time Combined Sewer Overflow (CSO) monitoring with site-specific development permits or regulatory tools like New York City's Unified Stormwater Rule (USWR). Case studies from South Bend, Buffalo, and Melbourne show that sensor networks and digital dashboards can enhance operational efficiency and system performance; however, these models rarely incorporate permit-level data or neighborhood-scale equity analytics that reveal how infrastructural benefits and burdens are shared.

Scholars, including Anguelovski et al. (2019) and Pearsall and Pierce (2020), emphasize that procedural justice, fair access to decision-making, is essential for equitable environmental planning. However, few operational systems turn these principles into practice when designing and managing hydrological monitoring tools. The Gowanus CSO Metrics Dashboard directly fills this gap by integrating permit-level metadata, rainfall-calibrated hydrologic modeling, and an equity-scoring module into a single interoperable platform. Unlike earlier approaches that mainly focused on efficiency or cost savings, this framework explicitly connects infrastructure performance to community vulnerability and regulatory compliance, defining equity as a measurable performance standard. Its modular design promotes transparency, allowing both residents and regulators to participate in oversight and make informed decisions about infrastructure planning.

By combining real-time environmental data with social and regulatory factors, the dashboard offers a repeatable model for cities aiming to incorporate data justice into stormwater management. The next section describes the methodological approach used to combine these elements and test the framework within the Gowanus Canal area.

Background / Case Context

The Gowanus Canal exemplifies the challenges faced by old urban watersheds impacted by aging combined sewer systems and industrial legacies. Once a major manufacturing corridor connecting Brooklyn's industrial area to New York Harbor, the canal has suffered over a century of pollution and hydrological shifts. Its designation as a federal Superfund site in 2010 by the U.S. Environmental Protection Agency (EPA) highlights the extent of contamination from industrial waste, petroleum residues, and untreated sewage overflows.

The Gowanus Canal sewershed spans approximately 1,758 acres of mixed residential, commercial, and industrial land uses, with over 90 percent served by combined sewers rather than a fully separated stormwater system (NYC DEP, 2024). Even small rainfall events—sometimes as little as 0.25 inches, can cause Combined Sewer Overflows (CSOs) through one of eleven active outfalls (EPA, 2024; NYC DEP, 2024). These discharges continue to pose threats to public health, degrade water quality, and complicate long-term cleanup efforts under the federal Superfund program. In anticipation of major redevelopment following the 2021 neighborhood rezoning, the City formalized several mitigation commitments through the Gowanus Points of Agreement (POA). Developed with input from the City Council, the POA outlines capital investments, interim management actions, and stormwater monitoring requirements for new construction. Oversight of these commitments is managed by the Gowanus Oversight Task Force (GOTF), a group of city agencies, elected officials, and community representatives that guarantees transparency and accountability.

The Unified Stormwater Rule (USWR), enacted in 2022, supports these local agreements by imposing stricter detention and retention standards on new developments across the city. In Gowanus, the rule oversees runoff from more than eighty proposed development sites, each required to submit a Site Connection Proposal (SCP) for review by the New York City Department of Environmental Protection (DEP). While these measures tighten regulations, the absence of real-time, publicly accessible performance data still hampers effective oversight—especially in historically under-resourced and environmentally burdened neighborhoods.

This convergence of federal cleanup mandates, city policy shifts, and community activism makes Gowanus an ideal testing area for equity-centered infrastructure monitoring. It demonstrates how multi-level governance, federal, city, and community, can be integrated through digital transparency tools to advance environmental justice within the constraints of legacy urban systems. The next Methods section details how this framework is applied through the design of the Gowanus CSO Metrics Dashboard.

Methods

The methodological design integrates quantitative modeling with conceptual framework development to promote transparency, accountability, and equity in Combined Sewer Overflow (CSO) monitoring. Three primary data streams were synthesized to support this framework. First, regulatory and permit datasets—such as Site Connection Proposals (SCPs) and State Pollutant Discharge Elimination System (SPDES) reports—must be compiled to establish a baseline of development-related discharge capacity and to map the spatial relationships between new construction and sewer loading. Second, hydrologic and hydraulic simulations must be conducted using the U.S. Environmental Protection Agency's Storm Water Management Model (EPA SWMM), calibrated specifically for the Gowanus sewershed to accurately represent system behavior and overflow patterns under various rainfall scenarios. Calibration parameters included sub-catchment area, imperviousness, and outfall rating curves acquired from NYC Department of Environmental Protection (DEP) records and site-level design submissions.

Third, rainfall normalization utilized long-term intensity–duration–frequency (IDF) data from NOAA Atlas 14 and NYC Rainfall Ready to adjust event thresholds and assess overflow risks amid changing climate conditions. Although localized community precipitation records are not yet available, the framework plans for future integration with CoCoRaHS or other community-based monitoring programs to enhance spatial detail and promote public participation in rainfall data collection.

These data streams inform four conceptual modules—Permit Compliance, Outfall Performance, Net Zero Progress, and Public Equity—which together comprise the CSO Metrics Dashboard. The dashboard can be built using a geospatial system with PostgreSQL/PostGIS for data storage and visualized interactively with Leaflet and D3.js. It provides rainfall-adjusted overflow alerts, monitors permit compliance, and evaluates site performance against Water Quality Volume (WQv) targets set under the Unified Stormwater Rule (USWR). Instead of just being a technical deliverable, the dashboard architecture acts as a conceptual bridge connecting regulatory modeling to participatory oversight. By aligning data integration, calibration, and visualization with environmental justice principles, the framework shows how real-time analytics can support transparent, community-understandable decision-making in urban stormwater management. The design is modular and adaptable, allowing it to be replicated in other legacy sewersheds that aim to combine equity-focused performance monitoring with regulatory compliance. Future plans include community involvement in rainfall data collection and dashboard interpretation, which will boost local stewardship and data justice within the Gowanus sewershed.

System Design and Modeling Framework

The CSO Metrics Dashboard is a data-integration platform that combines regulatory information, hydrologic-modeling outputs, and community-facing visualization tools. Using best practices in urban informatics, environmental sensing, and regulatory compliance, the dashboard creates a dynamic and participatory framework for stormwater management. It pulls together rainfall, flow, and permit data to support technical analysis and public accountability. Recent advancements in Internet of Things (IoT) technologies—such as wireless depth and pressure sensors, edge loggers, and cloud-connected SCADA systems—allow high-frequency measurements for real-time alerts, adaptive control, and clear visualization. Integrated into the dashboard's architecture, these tools connect operations data directly to community oversight and environmental justice goals.

Table 1. Core Functions of the Proposed CSO Metrics Dashboard

Function	Description
Data Integration	Integrate disparate stormwater and development datasets to create a unified, accessible platform.
Visualization	Visualize real-time and historical Combined Sewer Overflow (CSO) dynamics across drainage areas to gain better insight and inform decision-making.
Goal Tracking	Track progress toward achieving the *Net Zero CSO* goal as established in the Gowanus sustainability commitments.
Regulatory Reporting	Enable streamlined regulatory reporting and enforcement aligned with the Unified Stormwater Rule and EPA consent decree compliance.
Community Oversight	Support community oversight and equitable governance through transparent data sharing and participatory monitoring tools.

Note. This table outlines the five core functions of the proposed CSO Metrics Dashboard as conceptualized in this study. Each function is designed to enhance data integration, transparency, compliance, and equity in stormwater governance.

The dashboard is built on a geospatial architecture that combines a PostgreSQL/PostGIS database for managing spatial data with a web-based interface developed in Python, utilizing Leaflet and D3.js for interactive visualization. It ingests datasets from USWR reporting requirements and the Gowanus Oversight Task Force (GOTF) Points of Agreement, including parameters like permit numbers, PLUTO Lot IDs, sanitary and stormwater flow rates, allowable release thresholds, and Water Quality Volume (WQv) capacities.

Hydrologic and hydraulic modeling is conducted in EPA SWMM 5.1, calibrated to the Gowanus sewershed using topographic boundaries and impervious-surface data. Simulations incorporate rainfall scenarios from NOAA Atlas 14 and NYC Rainfall Ready projections for 2-year and 10-year design storms. Real-time control (RTC) logic is adapted from Xylem Vue deployments in Buffalo, Cincinnati, and South Bend, enabling dynamic flow management and overflow prediction.

Table 2. Technical Architecture and Key Data Inputs of the CSO Metrics Dashboard

Component	Details
Backend Architecture	PostgreSQL/PostGIS geospatial database
Frontend Interface	Web-based dashboard using Python, Leaflet, and D3.js
Primary Data Sources	NYC Unified Stormwater Rule (USWR) reports; Gowanus Oversight Task Force (GOTF) Points of Agreement; CoCoRaHS localized rainfall observations; NYC DEP Rainfall Ready data; NOAA Atlas 14 projections
Key Attributes Tracked	SCP Permit Number; PLUTO Lot ID; Sanitary Flow (gpd); Stormwater Flow Rate (cfs); Allowable Release Rate (cfs/acre); SMP Dimensions and Water Quality Volume (WQv); Anticipated CSO Reduction (gallons/year); SPDES Outfall Discharge Volume (mg/yr)
Modeling Platform	EPA SWMM 5.1 calibrated to the Gowanus sewershed
Storm Event Scenarios	2-year and 10-year design storms, using NOAA Atlas 14 and NYC DEP Rainfall Ready projections
RTC Decision Logic	Adapted from Xylem Vue deployments in Buffalo, Cincinnati, and South Bend
Validation Method	Comparison to DEP SPDES Annual Reports; ±10% tolerance over a 12-month rolling period
Alert Triggers	Flagged when projected sanitary discharge exceeds site WQv (USWR compliance threshold)

Note. This table outlines the technical and regulatory foundation of the CSO Metrics Dashboard, including data sources, modeling tools, and compliance mechanisms aligned with NYC's stormwater management strategy.

The design of the CSO Metrics Dashboard balances technical feasibility with regulatory and equity objectives. Its four modules—the Permit Compliance Tracker, Outfall Performance Map, Net Zero CSO Progress Tracker, and Public Equity Layer—address oversight gaps identified by the Gowanus Oversight Task Force. Based on existing municipal datasets (PLUTO, SPDES, SCP), the system guarantees interoperability with NYC DEP frameworks while allowing flexibility for future sensor and green infrastructure integrations. Including demographic indicators within the Public Equity Layer promotes procedural justice by connecting environmental performance with community representation, supporting findings by Scarlett et al. (2021) on the importance of inclusive participation in stormwater governance.

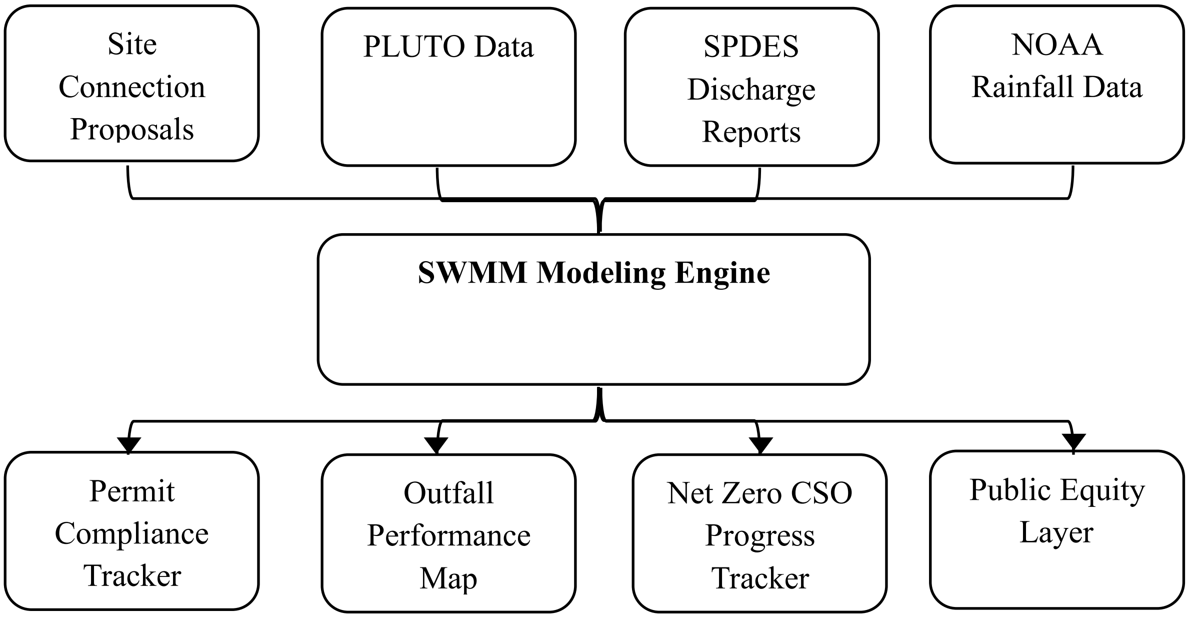

Figure 1. CSO Metrics Dashboard

Figure 1: Data flow architecture of the CSO Metrics Dashboard. Regulatory inputs (SCP permits, PLUTO parcels, SPDES outfalls) combine with rainfall observations (NOAA Atlas 14, NYC Rainfall Ready, CoCoRaHS) and the U.S. Environmental Protection Agency Storm Water Management Model (SWMM) to drive four public modules: Permit Compliance Tracker, Outfall Performance Map, Net Zero CSO Progress Tracker, and Public Equity Layer. This architecture supports near-real-time alerts, auditability, and participatory oversight.
Note. Iconography is schematic; data sources are listed in Appendix A.

To ensure long-term sustainability, the CSO Metrics Dashboard is entirely built on open-source software and offers exportable APIs for compatibility with City and third-party systems. Future integrations include the NYC DEP Green Infrastructure Annual Report database and the FloodNet sensor network. A community review process will also conduct biannual performance audits and facilitate structured public feedback loops, strengthening accountability and ongoing improvement.

Collectively, these features create a scalable, transparent, and equity-focused framework for stormwater governance that supports real-time compliance alerts, continuous data updates, and open-API access for researchers, regulators, and residents. Appendix A provides a detailed summary of the dashboard's data fields and regulatory elements, outlining inputs required under the Unified Stormwater Rule and Gowanus Oversight Task Force agreements that form the foundation for geospatial analysis, compliance tracking, and Net Zero CSO performance modeling.

Results and Expected Outcomes

The implementation of a centralized CSO Metrics Dashboard for the Gowanus Canal is projected to generate four primary categories of impact:

1. Enhanced Regulatory Compliance

By integrating site-level Water Quality Volume (WQv), anticipated sanitary flow, and Stormwater Management Practice (SMP) performance, the dashboard will support twiceyearly reporting in line with the requirements of the Unified Stormwater Rule (USWR) and the Gowanus Oversight Task Force (GOTF) agreements. Real-time flagging of parcels with sanitary discharge exceeding WQv thresholds will enhance proactive DEP enforcement and strengthen community accountability measures.

2. Progress Tracking Toward Net Zero CSO

Annual CSO volume projections for each outfall—based on SPDES permit data and SWMM modeling—can be compared to pre-rezoning baseline conditions. Summary metrics will measure cumulative reductions and evaluate if new development aligns with the City's Net Zero Carbon Strategy commitments.

3. Transparency and Procedural Justice

Public-facing dashboards, available in multiple languages and accessible formats, will display permit-level performance. Community members and environmental organizations will be able to monitor compliance and engage with data that was previously isolated in spreadsheets and agency reports. The integration of CoCoRaHS rainfall data further democratizes this process by allowing residents to contribute localized precipitation measurements, thereby improving model accuracy and building public trust in flood-risk projections.

4. Cost-Effective Infrastructure Planning

The CSO Metrics Dashboard will facilitate prioritization of stormwater retrofits, SMP installations, and grey infrastructure upgrades. Modeled scenarios will support cost-benefit analyses that align with EPA affordability criteria and local infrastructure investment frameworks. Based on assumptions from the Gowanus Neighborhood Rezoning Draft Environmental Impact Statement (New York City Department of City Planning & Department of Environmental Protection, 2021), implementation of the dashboard could verify approximately 5 million gallons per year (MGY) in CSO reductions from USWR-compliant development.

Applying proportional cost savings from Buffalo and South Bend, where smart stormwater management platforms avoided \$145 million and \$400 million in capital expenses, respectively (Xylem, 2024), the Gowanus framework could yield \$50–100 million in avoided infrastructure investments through fine-scale scenario testing and post-construction performance verification. A future modeling appendix or interactive dashboard layer could further calibrate these estimates by parcel, SMP type, or land-use classification, enhancing replicability and investment transparency.

Limitations and Considerations

The framework assumes consistent institutional data reporting, accurate sensor calibration, and uninterrupted real-time data flow—conditions that may be difficult to maintain in legacy infrastructure systems. Structural inequities, such as digital literacy gaps, language barriers, and uneven broadband access, could also impede equitable participation in the dashboard, especially among frontline communities. These limitations highlight the need for inclusive interface design, community-centered co-design processes, and ongoing system validation. Long-term trust, transparency, and resilience will rely on continuous public feedback, multilingual support, and training opportunities that enable residents to understand and act on localized stormwater data.

Discussion and Conclusion

These results indicate that Gowanus can transition from a compliance-focused reporting system to one based on performance-driven governance. Rainfall-normalized thresholds help lower false positives and negatives in event classification, enhancing the accuracy of overflow evaluations. Connecting permit-level metadata to demographic and spatial indicators increases transparency and makes the distribution of environmental burdens and benefits clear to both agencies and residents. Together, these features set the stage for third-party audits, targeted infrastructure upgrades, and clearer accountability toward the city's Net Zero CSO commitments.

The proposed Gowanus CSO Metrics Dashboard shows that technical monitoring and equity analysis can work together within a single, publicly available platform. By combining Site Connection Proposal (SCP) data, rainfall-adjusted thresholds, and real-time sensor inputs, the framework allows continuous assessment of how infrastructure performance impacts environmental justice outcomes. The model is designed to be adaptable for other legacy watersheds, providing a way for cities to integrate regulatory compliance with fairness in distribution and procedures.

Future efforts should improve the equity-scoring algorithm through community co-design, establish data governance protocols to safeguard privacy, and align dashboard outputs with evolving DEP and EPA reporting standards. Integrating the system with existing open-data platforms and expanding its sensor coverage will further boost reliability and public trust. Ultimately, this framework advances a participatory approach to urban water governance—one that connects infrastructure performance with social equity and resilience goals at the core of sustainable redevelopment in Gowanus and beyond.

Key findings include:

1. The critical role of permit-level metadata in identifying and tracing development-related burdens.
2. The need for dynamic, rainfall-calibrated thresholds to more accurately classify overflow events and avoid false compliance; and
3. The feasibility of constructing a CSO equity scoring module that links system performance to indicators of community vulnerability.

Together, these findings support broader efforts to advance environmental data justice through participatory governance. Future development of the dashboard should prioritize integration with the NYC DEP's Green Infrastructure Annual Report and FloodNet sensor network, establish independent audit protocols, and provide training for local stakeholders on data interpretation and oversight. These improvements will enhance both transparency and accountability, ensuring the dashboard evolves in tandem with climate risks and redevelopment pressures.

While rooted in the Gowanus Canal context, the principles underlying this framework—open data governance, participatory oversight, and climate-informed modeling—are applicable across diverse urban environments. Many cities worldwide face similar challenges of aging infrastructure, inequitable exposure to flooding, and fragmented data systems. From Copenhagen's Cloudburst resilience strategy to Singapore's Smart Water Grid and London's Thames Tideway program, integrated digital monitoring is increasingly recognized as essential for climate adaptation and social equity. The CSO Metrics Dashboard contributes to this global shift by demonstrating how real-time environmental data can be translated into transparent, justice-oriented governance tools. In doing so, it aligns with UN SDG 6.3 (Clean Water and Sanitation) and SDG 11.3 (Sustainable Cities and Communities), offering a roadmap for equitable, data-driven resilience planning in legacy urban watersheds worldwide.

Achieving Net Zero CSO in Gowanus is not only a technical or financial goal-it is a civic imperative. Aligning infrastructure modernization with environmental justice requires that data systems be transparent, participatory, and equitable. The CSO Metrics Dashboard provides a practical framework for realizing this vision by combining real-time data, regulatory compliance, and community-driven oversight. By embedding equity indicators and enabling transparent tracking of system performance, the dashboard transforms sewer governance from opaque and reactive to participatory and adaptive. This approach aligns with global and national mandates for inclusive infrastructure governance, including UN Sustainable Development Goal (SDG) 6.3, which seeks to improve water quality through pollution reduction, and SDG 11.3, which promotes participatory urban planning. It also supports domestic frameworks such as the Environmental Justice for All Act and the EPA's EJScreen initiative, both of which aim to address cumulative burdens in historically underserved communities. Moving forward, future iterations of the dashboard should prioritize multilingual accessibility, third-party audits, and inclusive training programs to ensure that all residents, not just the most connected, benefit from more intelligent and just infrastructure.

Table 3. Key Conditions for Replication of the CSO Metrics Dashboard in Other Urban Watersheds

Condition	Description
1. Standardized Permit Data	Development permit data must be consistently collected through formalized site connection proposals (SCPs) to ensure interoperability with the dashboard.
2. GIS-Defined Drainage Areas	Watersheds must have delineated drainage areas and mapped outfall linkages using GIS to enable accurate spatial modeling.
3. SWMM or RTC Integration	The replication site must support integration of EPA SWMM models or RTC (RTC) simulation engines for predictive analytics.
4. Institutional Transparency	Local agencies must commit to biannual public reporting and create mechanisms for community input, ensuring procedural equity and oversight.

Note. This table outlines the baseline technical, spatial, and governance conditions necessary to adapt the CSO Metrics Dashboard for use in other cities or watersheds.

Data Availability Statement

All datasets referenced in this paper, including Site Connection Proposal (SCP) permits, SPDES discharge reports, and rainfall records from NOAA and CoCoRaHS, are publicly available from the respective agencies or upon reasonable request from the author.

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[1] The USWR Properties dataset was sourced from the NYC Department of Environmental Protection (DEP) and includes all Site Connection Proposals (SCPs) filed within the Gowanus Sewershed since the adoption of the Unified Stormwater Rule in 2022. The dataset comprises parcel-level attributes, including permit ID, block and lot numbers, stormwater flow rates, sanitary discharge estimates, allowable release volumes, and green infrastructure metrics. It was obtained in CSV format via a public records request and processed for spatial integration using GIS software.

Table A1. Key Data Fields for CSO Metrics Dashboard

Field	**Description**
SCP Number	Permit reference from DOB for the site sewer connection
Site Address	Location of the development parcel
PLUTO Block/Lot	NYC parcel identifier
Sanitary Flow (GPD)	Projected sanitary discharge in gallons per day
Stormwater Flow (CFS)	Projected stormwater runoff in cubic feet per second
Stormwater Release Rate (CFS/acre)	Maximum allowable discharge per sewer type
Water Quality Volume (WQv)	Required treated volume for runoff management
SMP Type	Stormwater Management Practice (e.g., bioswale, tank, permeable pavement)
SMP Volume (CF)	Storage volume of the SMP
SMP Dimensions (LxWxD)	Physical dimensions of SMP
CSO Outfall	Connected CSO drainage area/outfall
Annual CSO Reduction (gallons)	Estimated reduction from SMP interventions

Table B1. Technical Glossary of Key Terms

Term	**Definition**
CSO	Combined Sewer Overflow – stormwater and sewage discharge during overflow events
DEP	NYC Department of Environmental Protection
USWR	Unified Stormwater Rule – NYC regulation for stormwater detention
WQv	Water Quality Volume – volume of runoff required to be treated or detained
SMP	Stormwater Management Practice – green or grey infrastructure for runoff control
RTC	RTC – dynamic monitoring and adjustment using sensors and models
SPDES	State Pollutant Discharge Elimination System – permit under the Clean Water Act
SCP	Site Connection Proposal – Sewer Connection Permit Application
FloodNet	NYC-based sensor network monitoring street-level flood conditions

Appendix A

Gowanus Canal CSO Outfall Inventory

Table A1. Gowanus Canal CSO Outfalls with Pipe Sizes, Coordinates, and Overflow Data

Outfall ID	**Location / Landmark**	**WRRF Service Area**	**Latitude**	**Longitude**	**Pipe Diameter (in)**	**Pipe Diameter (in/mm)**	**2008 Annual CSO Volume (MG)**	**Most Recent Overflow Events**	**Notes**
RH-034	Head of Canal	Red Hook	40.6781	-74.0123	48 in	48 in / 1219 mm	137.5 MG/yr	3 (2015)	Frequent overflow; upstream priority site
OH-007	2nd Avenue PS	Owls Head	40.679	-73.9968	72 in	72 in / 1828 mm	57.6 MG/yr	4 (2014)	High flow; monitored for

									bacteria; peak capacity ~146 MGD
OH-026	Butler Street	Owls Head	40.6788	-74.0055	42 in	42 in / 1066 mm	—	4 (2014)	Reclassified outfall; new ID as of 2013 SPDES
OH-003	Regulators 7A/B/C	Owls Head	40.6805	-73.994	Multiple (48–66 in)	Multiple (1219 mm–1676 mm)	372.8 MG/yr	—	Largest volume, priority in LTCP
OH-024	23rd St – 3rd Ave Relief	Owls Head	40.676	-73.9912	72 in	72 in / 1828 mm	26.4 MG/yr	—	Secondary contributor
OH-004	Regulator 7D	Owls Head	40.6795	-73.9952	36 in	36 in / 914 mm	5.9 MG/yr	—	
OH-005	Carroll St CSO	Owls Head	40.684	-73.9928	24 in	24 in / 609 mm	0.5 MG/yr	—	
OH-006	19th St – 3rd Ave	Owls Head	40.6825	-73.9936	36 in	36 in / 914 mm	15.6 MG/yr	—	
OH-023	Bush Terminal	Owls Head	40.6747	-73.9908	24 in	24 in / 609 mm	0.9 MG/yr	—	
RH-030	Red Hook CSO 4	Red Hook	40.6755	-74.0135	36 in	36 in / 914 mm	16.2 MG/yr	—	
RH-031	Red Hook CSO 3	Red Hook	40.6768	-74.012	36 in	36 in / 914 mm	16.7 MG/yr	—	

Note: This table lists all 11 permitted Combined Sewer Overflow (CSO) outfalls discharging into the Gowanus Canal. It includes their physical locations, pipe diameters (in both inches and metric units), WRRF (Wastewater Resource Recovery Facility) service areas, overflow volumes, and the most recent monitoring events. Data are sourced from SPDES permit documentation, NYC DEP's Long-Term Control Plan (LTCP), and annual CSO reports.