CSO Climate Change Preparedness

Conceptual Planning and Analysis Work Order 2

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King County

Protecting Our Waters

Doing our part on rainy days

Report Prepared by:
King County Wastewater Treatment Division
Murraysmith, Inc.
Cascadia Consulting Group
Barney and Worth, Inc.
Brown and Caldwell

For comments or questions, contact:
Janice Johnson
King County Department of Natural Resources and Parks
Wastewater Treatment Division
201 S. Jackson St.
KSC-NR-0503
Seattle, WA 98104-3855
206-477-5624
Janice.Johnson@kingcounty.gov

Alternative Formats Available

206-477-5371 (voice) or 711 (TTY)

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Acronyms

CD	consent decree
County	King County
CSO	combined sewer overflow
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ESJ	equity and social justice
GSI	green stormwater infrastructure
I/I	infiltration and inflow
LEED	Leadership in energy and environmental design
ROW	right-of-way
SPU	Seattle Public Utilities
WTD	King County Wastewater Treatment Division

List of Key Terms Used

Combined sewer overflow (CSO)

A combined sewer is one that has been designed to serve as a sanitary sewer and a storm sewer, and into which inflow is allowed by local ordinance. A CSO occurs when too much combined sewage flow caused by inflow is sent to a waterway from a combined sewer, rather than sent to the sewage treatment plant because the capacity of either the treatment plant or the combined sewer is exceeded.

Consent decree

A consent decree is a legal agreement that settles a complaint. In King County's case, the complaint is that uncontrolled overflows from its combined sewer system violate the federal Clean Water Act. The consent decree is a written agreement between King County, the Washington state Department of Ecology, the U.S. Environmental Protection Agency, and the U.S. Department of Justice that outlines the planned actions to resolve alleged violations of the law.

Green Stormwater Infrastructure (GSI)

Green stormwater infrastructure uses plants, trees, and soil to soak up the rain. It is designed to mimic nature by slowing or reducing polluted runoff close to its source. A successful GSI design captures and cleans polluted runoff from roads, roofs, and parking lots before it harms waterways. These solutions manage stormwater naturally and on-site, and compliment traditional "gray" infrastructure, like detention tanks and storage tunnels.

Infiltration and inflow (I/I)

"Infiltration" means the addition of groundwater into a sewer through joints, sewer material, cracks, and other defects. "Inflow" means the addition of rainfall-caused surface water drainage from roof drains, yard drains, basement drains, street catch basins, etc. into a sewer. Higher I/I increases the volume of water in the sewer system.

Infiltration

In hydrology and GSI design, infiltration refers to surface water drainage soaking into the ground, diverting it from the sewer system. In this context, increasing infiltration reduces the volume of water in the sewer system.

LEED certification

Leadership in Energy and Environmental Design (LEED) certification is a green building rating system administered by the United States Green Building Council.

RAND Corporation

A nonprofit institution that helps improve policy and decision-making through research and analysis. The name is derived from the phrase "research and development."

Real time controls

A system that performs control actions (for example, movement of gates, turning pumps on/off) in real time, adjusting the operation of facilities in response to changing conditions to maximize use of available conveyance and storage and avoid overflows.

Right-of-way (ROW)

A legal right, established by grant or permit, for a specific use of a land or property acquired for specific purposes. Most ROWs in King County are non-King County facilities and non-private lands. Transportation ROWs are typically wider than the pavement itself.

1.0 Introduction

Incorporating potential climate impacts into wastewater capital planning is an emerging topic that is affecting utilities across the nation. King County (County) Wastewater Treatment Division (WTD) sought to understand the state of these efforts to inform its own planning. Adaptation strategies identified through this effort are intended to assist WTD in preparing for and adapting to climate change in its capital program.

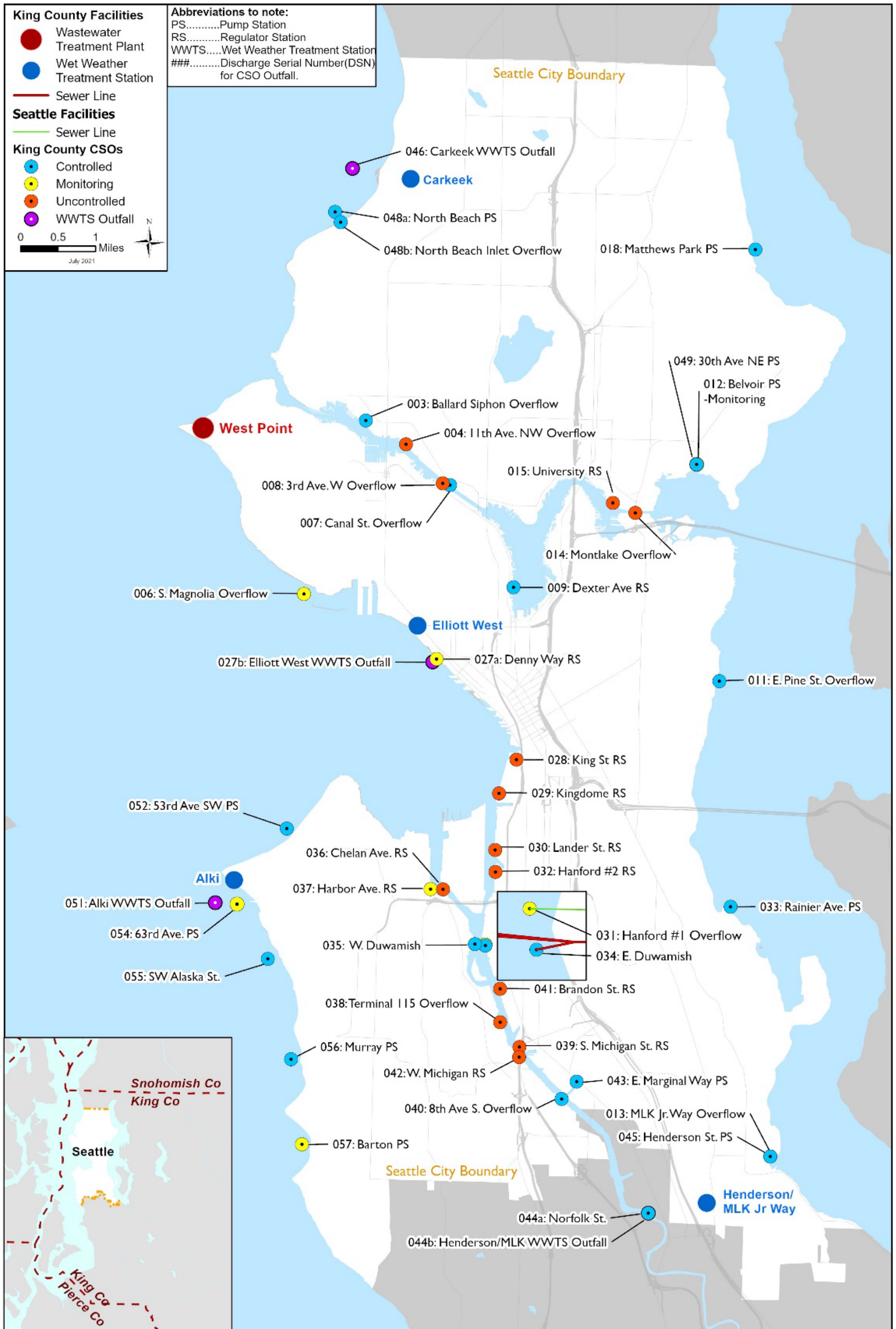
The body of the report highlights key findings of the project tasks and is not meant to include comprehensive details of all work tasks.

1.1 Background

King County provides wholesale wastewater conveyance and treatment of flows from 17 cities, 16 local sewer utilities, and one tribal government.

Wastewater flows to WTD's regional system from the City of Seattle and 33 other component agencies. The newer parts of WTD's service area use separate pipes to convey wastewater to WTD's system and stormwater to local receiving water bodies. Much of Seattle is served by a combined sewer system that conveys wastewater and stormwater runoff in the same pipes. WTD's responsibility begins where Seattle's pipes have collected sewage from areas of 1,000 acres. WTD conveys most of the flow from Seattle (including most of the combined sewage flows) to West Point, located in Discovery Park. A small amount of sewage from Seattle is treated at WTD's South Treatment Plant in Renton.

When large storms occur, and flows exceed the capacity of the County conveyance system, CSOs may occur at any of the 39 County CSO locations that discharge to Lake Washington, Lake Union, the Lake Washington Ship Canal (Ship Canal), the Duwamish River, Elliott Bay, and Puget Sound (Figure 1). CSOs may also occur at Seattle's 82 CSO locations in their local sewer system. Seattle Public Utilities (SPU) is responsible for separately managing and reporting on those locations.



King County
Department of Natural Resources and Parks
Wastewater Treatment Division

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Data Source: WTD GIS, GIS Center

King County Combined Sewer Overflow (CSO) Locations

Utilities typically size combined sewer infrastructure by using historical rainfall patterns to estimate future runoff. Sizing infrastructure to collect, convey, store, or treat future runoff will limit the frequency and volume of untreated CSO events. WTD is planning, designing, and constructing CSO control projects in accordance with the 2013 consent decree (CD) between the County, the United States Department of Justice, United States Environmental Protection Agency (EPA), and the Washington Department of Ecology (Ecology). Ecology evaluates compliance of a CSO outfall with a performance standard of not more than one untreated discharge event per outfall per year on a 20-year moving average. WTD manages 39 CSO outfalls within the City of Seattle in accordance with the National Pollutant Discharge Elimination System permit (WA0029181), which outlines the performance standard.[1]

Incorporating the impacts of climate change influences the planning, design, and operation of combined sewer systems. Future rainfall patterns are predicted to deviate from historical norms, introducing uncertainty in facility sizing decisions and making the important work of clean water more challenging. Current science models predict drier summers and wetter winters for the Pacific Northwest. Changing winter rainfall could lead to increased stormwater flow in the combined sewer system, which would lead to the need for larger combined sewer facilities to meet Ecology's once-per-year standard. Changing rainfall or sea level rise could also impact facilities already built that did not account for future climate impacts. Sea levels are also predicted to rise, which can impact the performance of a CSO site by affecting hydraulic considerations, limiting conveyance capacity, or causing saltwater intrusion into the sewer system. Considering these potential impacts, WTD is evaluating options for planning and designing future CSO facilities.

1.2 Purpose

The purpose of this project was to gather information on how peer wastewater agencies across the United States and Canada are incorporating climate change impacts into their capital delivery process. This effort involved performing agency interviews and literature reviews to understand current studies and practices around climate mitigation approaches for CSO infrastructure.

The project scope included two main tasks:

- **Conduct Agency Interviews:** Developed a list of questions and conducted interviews with peer wastewater utilities from across the United States and Canada. Interviews with 10 agencies focused on identifying strategies used to develop and implement climate change adaptation plans for planning and design of CSO infrastructure. This work took place March through June of 2021.

[1] Ecology issues the NPDES permit for WTD's West Point Treatment Plant that stipulates the performance standard for CSO outfall. The NPDES permit is in compliance with both the State of Washington Water Pollution Control Law Chapter 90.48 Revised Code of Washington and the Federal Water Pollution Control Act.

- **Perform Literature Review:** Reviewed industry publications (including peer-reviewed journals, government publications, water and environmental associations, and other published materials) to explore existing practices of wet weather management and climate change adaptation strategies for CSO infrastructure. Impacts included changing rainfall patterns, changing wastewater volumes and flow rates, equity and social justice, and sea level rise. The review was limited to 15 sources and took place between March and June of 2021.

The following sections detail the process and results of the interviews and literature review.

2.0 Agency Interviews

The project team interviewed wastewater utilities that will likely face similar challenges incorporating climate change impacts into their CSO management as WTD. Fifteen agencies across the United States and Canada were contacted, and 10 were interviewed. The list of questions used to guide the interview discussion is included in Appendix A.

Sections 2.1 through 2.3 identify the peer agencies, summarize interview topics, and present the key findings from the interviews.

2.1 Peer Agencies

The interviewed agencies were selected based on a variety of factors including geography, utility size, CD obligations, population growth, and participation in organizations such as the Water Utility Climate Alliance.[2] Additionally, given the consistent joint coordination between WTD and SPU on climate adaptation efforts, SPU was not included as an interviewee. The following 10 agencies agreed to participate in this project:

- Narragansett Bay Commission, Narragansett, Rhode Island
- New York City Department of Environmental Protection, New York City, New York
- East Bay Municipal Utility District, Oakland, California
- The City of Portland Bureau of Environmental Services, Portland, Oregon
- City of Vancouver, Vancouver, British Columbia, Canada
- Pittsburgh Water and Sewer Authority, Pittsburgh, Pennsylvania
- City of Peoria Public Works Department, Peoria, Illinois
- Greater Peoria Sanitary District, Peoria, Illinois
- Northeast Ohio Regional Sewer District, Cleveland, Ohio
- City of Atlanta Department of Watershed Management, Atlanta, Georgia

Five other agencies were contacted but were unable to participate.

- Allegheny County Sanitary Authority, Pittsburgh, Pennsylvania
- District of Columbia Water and Sewer Authority, Washington, D.C.
- City of Kansas City, Kansas City, Missouri
- Metro Water Services, Nashville, Tennessee
- Philadelphia Water Department, Philadelphia, Pennsylvania

[2] More information about Water Utility Climate Alliance can be found at https://www.wucaonline.org. The stated mission of this organization is “collaboratively advancing water utility climate change adaptation.”

2.2 Agency Interview Topics

The project team developed a list of questions to gain insight into how each agency approaches its combined sewer/wastewater programs—and what role, if any, climate change impacts affect those programs. The questions were organized into the following topics:

- Quantifying the impacts of climate change and managing uncertainty
- CSO reduction plans
- Financing and financial assumptions
- Regulatory environment and flexibility
- Equity and social justice (ESJ) and public involvement

Interview Format

Each interview lasted approximately one hour with multiple representatives from peer agencies. Prior to the interview, the project team emailed pre-interview and interview questions to each participating agency (see Appendix A).

Seven agencies responded to the pre-interview questions, with varying levels of detail and completeness; for the remaining agencies, the interviewers asked both sets of questions during the phone interview. The interview responses were generally qualitative in nature (for example, discussing changing rainfall patterns without discussing specific rainfall volumes or intensities). The topic areas addressed, and the length of time spent on each topic, varied based on each agency's experience and expertise.

This report highlights information collected during one-hour interviews along with written responses to questions on a complex topic and as a result, information may be limited.

2.3 Key Findings and Summary of Agency Interviews

Key findings from agency interviews are compiled by topic area below. Traditional gray infrastructure such as heavy utilization of engineered storage tanks and piped conveyance is the most common method used to control CSOs. Many interviewed agencies are also implementing green stormwater infrastructure (GSI) solutions to manage stormwater runoff in combined sewer areas. Additionally, several interviewed agencies also have the authority to manage stormwater within their service areas, and stormwater management techniques are part of their CSO control strategy as well.

Discussions revealed that climate change impacts had not been a key consideration for utilities' planning until more recently, and many agencies are still considering their approach to incorporating climate change projections into their CSO and wastewater programs. Regardless, the agency interviews did provide insight into peer agencies' approaches to the capital and operating aspects of their combined sewer and wastewater systems. Although few of these strategies relate to climate change directly, the interview did include discussions of ideas and practices that address broader concerns.

Interview Topic Area 1: Quantifying the impacts of climate change and managing uncertainty

Quantifying the impacts of climate change and managing uncertainty are important considerations that can influence infrastructure sizing and cost, technology use, and operating strategies. The interviewed peer agencies are in different stages of quantifying the impacts of climate change; therefore, responses on this topic varied between peer agencies. The following highlights some of the discussion with agencies on this front.

Resilience and vulnerability studies: Resiliency reports and vulnerability assessments are tools commonly used to document potential challenges and risks from climate change such as sea level rise and increased risk of flooding. Some agencies noted more focus on rising sea levels rather than changing rainfall patterns (East Bay, Narragansett, and New York). For example, East Bay noted that its Wastewater Climate Change Plan (June 2020) identifies rising seas as a greater threat to its system than changing rainfall. Rising seas can impact wastewater infrastructure assets causing accessibility issues to and around facilities and possibly inundating equipment. The District has studied these impacts and how to design around their potentials as sea levels rise. WTD has conducted similar studies since many WTD facilities are exposed to tidal waters.

Design guidance: Design guidance is important so that agencies have direction for implementing planning considerations, such as accounting for the projected impact of climate change, into the design and construction of infrastructure. New York discussed two resources that guide consideration of climate change in its infrastructure design process. The *Climate Resiliency Design Guidelines* published by the New York City Mayor's Office of Resiliency offers approaches for three impacts associated with climate change: increasing heat, increasing precipitation, and sea level rise. The guidelines recommend adaptable design as a key tool to manage uncertainty. Adaptable design is defined as "a specific kind of resilient design that provides a useful, iterative approach for managing uncertainty and designing resilient facilities." (Climate Resiliency Guidelines, 2020) The guidelines illustrate adaptable design with an example of an emergency generator on an elevated pad. The height of the pad should match the projected sea level for the generator's useful life, but the foundation should be sized to support the much higher pad that will be required by the end of the adjacent building's useful life.

The New York guidelines also recommend that designs pair decadal (2050, 2080, 2100) climate change impact projections to the useful life of the asset. Facilities that have a more adaptable design can accommodate shifting climate change impacts than those for which adaptable design is difficult.

Additionally, New York City Local Law Intro 2092, adopted April 18, 2021, requires that the New York City's Office of Long-Term Planning and Sustainability develop further resiliency design guidelines, as well as a climate resiliency score metric used to ensure projects over a certain construction cost threshold meet the requirements.

Lastly, Portland discussed forming an internal Resiliency Team to review capital projects and make sure climate resiliency goals are consistently being met during the planning, design, and construction of facilities.

Rainfall projections: Accounting for changing rainfall in facility sizing was not a common practice historically among peer agencies at the time of the interviews. Based on interview responses, relying on historical data—and not adopting new models with rainfall uncertainty—is a product of the regulatory environment and the expectation that utilities use existing models (see Regulatory Environment and Flexibility section for more detail). Updated rainfall models could result in differently sized pipes and other features. Northeast Ohio mentioned that its modeling assumes uniform distribution of rainfall across the system, which adds conservatism to sizing since CSOs are often driven by locally intense thunderstorms. Northeast Ohio also noted in its interview response that it considers current climate projections too variable to be acted on in capital project planning and design. WTD has worked with the University of Washington's Climate Impacts Group to increase confidence in rainfall projections used for facility sizing (Swarner et al. 2020 Draft Report).

GSI programs: Agencies did recognize that reducing uncertainty in sewer system operations and performance and improving sewer system resilience is important. Many agencies noted that they are implementing, or are planning to implement, GSI programs to mitigate uncertainty around climate change impacts to runoff generated by rainfall. For example, GSI could be implemented to capture excess runoff if the installed gray infrastructure is undersized for increased rainfall intensities and/or volumes.

Risk-based infrastructure sizing: One approach to managing uncertainty is using a risk-based approach to infrastructure sizing. A risk-based approach allows decision-makers to identify a risk tolerance for a given project (or for an agency overall) to make investment decisions. Portland, Northeast Ohio, and Atlanta discussed risk-based approaches to facility sizing—for example, checking the marginal cost of providing a higher level of service for a given project than the design standard.

Interview Topic Area 2: CSO reduction plans

The project team asked peer agencies about their control standards to understand how they reduce or control CSOs in the face of climate change. The utilities interviewed had multi-year CSO reduction plans and programs (East Bay has a program that manages and maintains a separated sewer system with high I/I; therefore, it manages wet weather issues like a combined sewer system). Similar to WTD, many utilities have historically built, or are currently designing/building, gray infrastructure projects to manage CSO flows. The interviewees discussed their CSO reduction plans, stormwater management techniques, and system optimization strategies.

Sizing decisions: Agencies were asked how they achieved internal consensus on sizing decisions for CSO control infrastructure because there is no national guidance on this topic. WTD uses model simulations during planning and design to help demonstrate that a proposed facility will meet Ecology's once-per-year CSO standard. Storm characteristics are a critical input into the models that WTD uses. Until recently, WTD used information from the historical rainfall records as the input into its models ultimately serving as the basis for facility sizing. However, this practice may result in undersized facilities if future rainfall is more frequent, intense, or of larger volume than the historical record used for facility sizing. Climate science predicts increased rainfall intensity during the winter in the Pacific Northwest, yet Ecology has not provided guidance on incorporating climate impacts in sizing facilities. The once-per-year performance standard that Ecology currently uses does not allow for changing rainfall patterns over the life of a facility.

In contrast, peer agencies felt they had more confidence in designs achieving CSO compliance even if a future storm is larger than storms originally used for facility sizing. Those interviewed described working to get regulatory buy-in on using a design storm or a “typical year” of rainfall from the historical rainfall record for facility sizing. Facility sizing did not have to account for future storms larger than those used for facility design. Setting design criteria to a fixed storm size (or a fixed series of storms) provides clarity and guidance on what designs would achieve compliance. Under this arrangement, a CSO triggered by a larger than ‘typical’ storm is not necessarily a compliance violation. Climate-change driven variations in precipitation are therefore less likely to trigger compliance violations for the peer agencies interviewed. As such, interviewees had no feedback on statistical or engineering methods to incorporate uncertainty about future precipitation into facility sizing decisions. Additionally, the peer agencies interviewed did not offer insight into how the design storm or “typical year” rainfall might differ had climate change been included in the design process.

The City of Atlanta indicated that it completed all major CD projects in its CSO area in 2007. The projects Atlanta constructed consisted of deep storage facilities and sewer separation. Atlanta noted that it accounted for anticipated impacts of changing rainfall patterns due to climate change in modeling during the design of those facilities. The agency shared that it believed that incorporating climate change considerations in the planning and design process resulted in the facilities being appropriately sized, and they are currently in compliance. Additionally, regulators have allowed Atlanta to use GSI to add system resiliency and reduce surface flooding in areas served by a combined sewer system.

Stormwater management techniques: Stormwater management techniques, such as limiting runoff from re-development flowing into a combined sewer system, were commonly discussed strategies used by agencies to reduce CSOs. Stormwater volume is a driver of CSOs, so having the ability to manage stormwater flows in a combined sewer system is another means to reduce CSO volumes overall.

The interviewed agencies differ in the policy tools they have available to manage stormwater. New York, the City of Peoria, Portland, Northeast Ohio, and Pittsburgh have the authority to manage stormwater directly by enforcing stormwater codes. Northeast Ohio has found that many developers redeveloping parcels within its service area are pursuing LEED certification, which provides incentives to reduce stormwater flow into the combined system.

Narragansett Bay Commission and Greater Peoria Sanitary District are similar to WTD in that they are wholesale utilities whose local agencies have primary responsibility to manage stormwater. SPU’s Stormwater Management Code regulates stormwater runoff in the only combined sewer system served by WTD. As a wholesale utility, WTD may not have the same opportunity to reduce CSOs by implementing or revising stormwater management code requirements as many of the peer agencies interviewed.

Some agencies use code requirements for sewer laterals and private downspouts to better manage stormwater. Excess water can enter combined sewer systems through cracks and joints in sewer laterals. Downspouts collect stormwater from rooftops and can discharge to combined sewer pipes in some areas. East Bay has a program called “The Private Sewer Lateral Program” that requires lateral inspection and repair with every home sale. In the San Francisco Bay area (East Bay Municipal Utility District jurisdiction), working on a lateral is a small percentage of home price. Peoria shared that it explored a similarly code-driven downspout disconnection program, but ultimately decided that the marginal cost of requiring downspout disconnection was too great relative to the lower home prices in the area, so it did not implement the program within the city. RainWise is a joint WTD and SPU program that encourages residents to redirect downspouts that collect rainfall from rooftops to a GSI feature. The GSI feature allows this runoff to be infiltrated back into the ground rather than discharging into the combined sewer system.

System optimization: Another approach to reducing CSOs is through system optimization. This approach attempts to maximize the use of the existing capacity in the system before a CSO occurs. WTD has widespread use of real-time controls in its combined sewer system to optimize performance. Two agencies mentioned the use of real-time controls in combined sewer systems. These agencies, New York and Northeast Ohio, expressed a preference for passive controls where possible due to perceived high operation and maintenance needs of real-time controlled assets. One of the agencies the project team was not able to set up an interview with—the City of Kansas City, Missouri—is pursuing a CSO control strategy with heavy reliance on real-time control, according to the website.

Interview Topic Area 3: Financing and financial assumptions

WTD analysis has indicated that climate change will likely increase the size of infrastructure needed to control CSOs to meet regulatory requirements and protect waterways. The analysis is documented in *Modeling of Possible Future Climate Change Scenarios* (Swarner et al. 2020 Draft Report). Larger facilities would lead to increased costs. WTD was interested in how other agencies fund infrastructure in the face of rising costs. Interviewees discussed funding options, rate impacts, and grant programs.

Funding options: The responses and discussions under this topic indicated that traditional funding mechanisms (e.g., bonds, rates, and federal and state loans) to fund combined sewer programs and projects were most common among the agencies interviewed. There was little indication that more innovative funding measures, such as those specifically geared towards “green” investments, were currently being pursued by the agencies interviewed.

Rate impacts: Some agencies indicated that rate increases are necessary to keep up with rising costs of construction and that there are cost burdens associated with delivering CSO projects as required under CDs. New York noted that early investment in CD-driven CSO projects resulted in limited funding for other needs (such as stormwater) and future projects, limiting potential holistic approaches to CSO control (for example, a combination of traditional gray projects with stormwater separation and/or GSI). Similarly, Portland noted that funding large CSO storage pipes resulted in the need to defer other projects.

Several agencies indicated they have programs to reduce utility bills for lower income populations. The topic of leveraging affordability—what level of CSO control a utility and its rate payers can reasonably afford—was noted as a key negotiation topic with regulators for those agencies with CDs.

Grants: Northeast Ohio discussed two in-house grant programs, which are funded out of the sewer rates it collects. The larger program sets aside $7 million to $15 million dollars for competitive grants to member communities. This program funds upgrades and maintenance of collection systems to reduce flows entering the regional sewer system managed by the Northeast Ohio Regional Sewer District. The second grant program has $2 million available per year for developers or member communities to incentivize implementation of GSI. Northeast Ohio thinks that these programs build system resiliency (note: limited interview time meant that further details of the implementation and long-term success of these programs were not explored).

Interview Topic Area 4: Regulatory environment and flexibility

Each agency operates under different regulatory environments based on state, local, federal, and CD requirements (if applicable). The Ecology regulation limits each WTD outfall to one CSO per year on a 20-year moving average. This regulation does not explicitly call for consideration of climate change in facility planning; however, accounting for changing rainfall patterns is likely necessary to meet Ecology's performance standard. A facility sized to limit CSO events must meet the frequency regulation regardless of whether climate change causes rainfall intensities or volumes to increase in the future. The project team discussed regulatory climate change considerations, CDs, and vulnerability assessments with the interviewed peer agencies.

Regulatory climate change considerations: Agencies did not report requirements by regulators to include climate change considerations in CSO sizing or programs from a state or federal level. Factoring for climate change in capital projects instead stemmed from local regulations (New York), internal agency initiatives (mainly New York and Portland), local observations of rainfall trends (Pittsburgh, Atlanta), and potential sea level rise impacts (New York, East Bay, Narragansett).

Atlanta was the only interviewee that described an event-based definition similar to Ecology's regulation. CSO control of four overflows per three years per outfall is the requirement that Atlanta faces. There is a risk of not meeting frequency limits for event-based CSO requirements if future storm events are larger than those used for facility sizing. Atlanta has completed CD driven projects and is currently in compliance as discussed in the Sizing Decisions section above.

Consent decrees: Almost all agencies interviewed have, at some point, entered into a CD with the EPA and the United States Department of Justice that has defined their combined sewer programs. Some agencies described challenges in negotiating flexibility into their CDs. Depending on the type of CD and the EPA region overseeing the enforcement, agencies reported different levels of effort to modify project details. For example, some agencies reported small changes in facility design as it advanced from concept to final design required detailed negotiations. Other agencies reported that requests to defer projects to address a maintenance backlog were met with requests for substitute projects that would yield no cost savings.

New York discussed evaluating dual use facilities to integrate multiple drivers such as CSO control and increased system resiliency for more efficient use of funding sources. However, the agency indicated that it faced pressure from the regulatory environment to follow pre-defined project schedules from its CD rather than revaluating mutually beneficial opportunities. Atlanta noted it is allowed to utilize stormwater management to provide system resiliency and solve localized flooding issues in the combined sewer area and to stay on target with CD requirements.

Vulnerability assessments: East Bay initiated a study of climate change impacts on its wastewater system (*Wastewater Climate Change Plan*, June 2020). The plan evaluates mitigation strategies, vulnerabilities, and adaptation strategies for the risks associated with climate change. Identified risks for East Bay include sea level rise, increased risk of wildfires, and changing weather patterns.

The State of California also requires cities and counties to adopt a general plan that includes a vulnerability assessment as part of SB 379 (Climate Adaptation and Resiliency Strategies). These vulnerability assessments identify climate risks, set risk adaptation and resiliency policies, and identify feasible implementation measures. In the state of California, a general plan is a document that includes a local government’s plan to meet a community’s long-term vision.

Interview Topic Area 5: Equity and social justice and public involvement

Equity and social justice (ESJ) and public involvement are key considerations when planning and implementing WTD capital projects. Each of the agencies interviewed had its own approach to these topics. Discussions with agencies focused more on public involvement efforts rather than addressing ESJ issues as part of their engagement; however, interviewees acknowledged that ESJ is an important consideration. The agencies did not discuss equity concerns related to equitable use and/or impacts from use of the waterways with CSO discharges, such as swimming, fishing, or boating. The discussions primarily involved informing communities of CSO impacts and projects, incorporating feedback and participation from the community, and unintended consequences of GSI implementation.

Public outreach: All interviewees discussed holding meetings with stakeholders and/or receiving feedback from community interest groups and elected officials. The considerations and approaches are summarized below:

- Atlanta, Peoria, Greater Peoria Sanitary District, Narragansett Bay, New York, and East Bay did not describe an outreach program specific to CSOs focused on reaching communities of color.
- New York noted that there are larger ESJ issues associated with plant siting and truck traffic (for solids disposal) than CSOs.

- Northeast Ohio discussed neighborhood level outreach plans. These were not explicitly focused on reaching underserved communities but tended to because of the location of CSO outlets in lower-income neighborhoods.
- Pittsburg and Vancouver (Canada) declared their intent to center ESJ concerns in planning CSO projects but indicated that they are still working out implementation.
- Portland incorporates equity explicitly into its planning process when comparing proposed alternatives. This agency described considering the disproportionate impacts under-served communities would bear in the event of a service failure.
- Portland discussed releasing media alerts after CSO events to alert the public of potential hazards near recreational areas.

Incorporating the community: Northeast Ohio discussed a program that incorporated members of communities impacted by CSO projects into the project team. The program served multiple purposes, including developing professional skills of participating community members (interviewees noted that some participants had eventually found employment with public agencies based on this experience) and developing project ambassadors to provide information back to communities where they lived. Both Narragansett Bay and Northeast Ohio discussed the importance of building community amenities, such as parks on top of land used for underground infrastructure projects. Similarly, Atlanta mentioned its Old Forth Ward Capacity Relief Project. This project incorporates stormwater control infrastructure with public park features.

Unintended consequences of GSI implementation: Vancouver (Canada) noted that GSI programs may have contributed to an unintended consequence of gentrification in neighborhoods that received infrastructure improvements. Peoria noted that some communities expressed a similar concern when green projects were introduced during community outreach efforts, while others found the ancillary benefits of a GSI-focused approach attractive.

3.0 Literature Review

The project team reviewed published literature for information on effective climate change adaptation strategies for planning and designing CSO infrastructure; successful case studies for managing, maintaining, and developing resiliency for CSO infrastructure; and ESJ issues specific to CSOs. This review was intended to inform WTD on current strategies, methods, and findings related to climate adaptation and CSO facilities and to facilitate workshop discussions by introducing participants to techniques that could be adopted by WTD.

3.1 Selection Method

The project team used keyword searches of major literature databases to canvas the literature broadly and then selected papers based on the relevance of their results to WTD and the usefulness/adaptability of their methods to WTD. Based on their professional experience and prior work, the project team supplemented papers identified via database search with other sources. Following a forward citation search (searching for newer papers that list a given paper in their references) on a subset of the selected papers to include the most current research in the literature review, the project team read the papers in their entirety and summarized the key points in this report.

Some active research topics were excluded because the County is already familiar with their findings. For example, WTD's modeling team has been working on climate-related hydraulic projections for several years (Swarner et al. 2020 Draft Report). Therefore, articles that discussed how to downscale a global climate model for local application were not included in the literature review. Similarly, while selected papers considered the systemic effectiveness of GSI for CSO reduction, the large body of literature examining the performance of a single GSI installation or discussing the design principles of different GSI types was not reviewed.

A scope assumption for this task limited the review to 15 articles. The project team ultimately selected 12 peer-reviewed articles, an unpublished thesis and two research reports. A list of the 15 selected papers along with a brief synopsis of each is presented in Appendix B. It is recommended that readers refer to the cited articles to further understand or implement a strategy or concept as the summaries below may not be exhaustive.

3.2 Key Themes from Literature

The material reviewed fell into three main themes relevant to WTD's CSO program:

- Effectiveness of GSI in reducing CSOs
- ESJ and public involvement impacts
- Decision-making under uncertainty

The key themes from the literature review are presented below.

Literature Review Theme 1: Effectiveness of GSI in reducing CSOs

Seven of the peer-reviewed articles focused on evaluations of the effectiveness of GSI in reducing CSOs. Two main findings emerged:

- Modeling studies that analyzed different approaches—such as GSI in the right-of-way (ROW) versus private installation and different GSI types under different climate scenarios—showed potential for volume reduction to CSOs using GSI.
- It is difficult to quantify volume reductions from GSI in real-world observations at the watershed scale due to spatial and temporal variability of rainfall and variability of land use across a watershed.

The potential to reduce peak runoff to a combined sewer system makes GSI an attractive option for reducing CSOs. Reviewing literature on GSI effectiveness is important because WTD includes GSI as an option for its CSO infrastructure projects. Also, as discussed in the Agency Interviews section, GSI is potentially an option for increasing system resiliency given changing rainfall patterns associated with climate change.

WTD has experience demonstrating the effectiveness of GSI using modeling, so selected articles were not necessarily focused on modeling methodologies. Rather, selected articles focused on assessing the potential of GSI implementation at a watershed or utility scale to achieve CSO reduction targets.

GSI approaches: GSI refers to an assortment of strategies to either temporarily detain peak runoff in urban areas or permanently reduce it (for example, by increasing infiltration or evaporation), rather than the traditional “gray” approach of directing stormwater into a piped sewer system (Fischbach et al. 2017). GSI strategies include small-scale modifications to individual homes, such as rain barrels or rain gardens; medium-scale installations in the public ROW, such as bioretention and permeable pavements; or large-scale detention ponds. These strategies can also deliver water quality benefits besides flow quantity reduction.

Two modeling studies of midwestern cities suggest that rainwater harvesting on private property could achieve all or a substantial fraction of volume reduction targets (Chen et al. 2019 and Tavakol-Davani et al. 2016). Agencies might face challenges in relying on rainwater harvesting on private property to meet CSO compliance requirements, however. Private property owners might remove or neglect to maintain the GSI, thereby threatening an agency’s ability to maintain CD compliance.

Other modeling studies found that GSI would not achieve CSO reduction targets under future climate conditions for their studied cities. A study of the Pittsburgh area examining a range of gray, green, and hybrid stormwater options found that none of the options were sufficient to eliminate CSOs with increased rainfall due to climate change. The cost effectiveness of GSI increased in the climate scenarios that used higher rainfall projections, however (Fischbach et al. 2017).

Hou and colleagues modeled the impact that proposed green and gray stormwater projects had on widespread urban flooding problems for a city in northeastern China. The researchers found the proposed projects would keep urban flooding problems from worsening with increased rainfall due to climate change but would not be sufficient to reduce urban flood risk to acceptable levels (Hou et al. 2020).

Watershed scale effectiveness of GSI: Two papers, Shuster and Rhea (2013) and Pennino, McDonald, and Jaffe (2016), focused on real-world impacts/effectiveness of GSI at the watershed scale. The project team only found these two papers on this topic, despite looking with both key word searches and tracing the paper citations to see if updated work was available. The papers indicate that demonstrating real-world effectiveness at the basin or utility service area scales may be difficult. Some reasons for this difficulty include spatial and temporal variability of rainfall and variability of land use across a watershed. Projects require thoughtful planning and implementation of a monitoring approach to track efficacy. This topic is important because predicting and demonstrating the effectiveness of GIS is critical to WTD’s regulatory reporting.

Shuster and Rhea conducted an experimental study in suburban Cincinnati that measured watershed-level impacts of rainwater harvesting on detention and runoff volume. The authors found a correlation between installation of GSI and stream discharge, but the size of the impact was small (Shuster and Rhea 2013). The study area was residential with a low percentage of impervious surface (14 percent), so the results might not translate to areas with more impervious surfaces.

In contrast, the study by Pennino, McDonald, and Jaffe (2016) used an observational approach to look at real-world watershed-level impacts of GSI in the District of Columbia and Baltimore areas. Using publicly available data, the authors compared hydrology (23 watersheds), water quality (13 watersheds), and CSO volume (43 sewersheds) in watersheds with different amounts of GSI. The study did not find a relationship between CSO volume and percent of the watershed served by GSI. The analysis showed potential for GSI to reduce peak flows in receiving waters; however, there were diminishing returns (specifically, going from 10 percent to 60 percent of watershed tributary to GSI does not reduce peak flow much more). Additionally, the investigators were not able to show reduction in flashiness in individual watersheds as more GSI was built over time.

The difficulty demonstrating benefits of GSI at broad spatial scales under real-world conditions is a consideration for WTD in using GSI in planning efforts to meet CSO reduction requirements. However, only two articles were available for this topic.

Literature Review Theme 2: ESJ and public involvement impacts

Two articles covered important ESJ factors to consider when planning CSO compliance programs:

- The distribution of CSO outfalls and the financing of system upgrades can have equity implications.
- There is a need for greater public engagement to reduce the impact of CSOs on affected communities.

These two factors directly relate to the WTD CSO program. WTD is committed to addressing equity and social justice concerns for outfall locations in historically disadvantaged neighborhoods such as in south Seattle along the Lower Duwamish waterway.

CSO distribution and system financing: Studies revealed equity implications related to both the distribution of CSO outfalls and financing of system upgrades. One study of the Mystic River watershed near Boston found that CSO discharge disproportionately affects low income and Black, Indigenous and People of Color (BIPOC) communities. There was a smaller imbalance in impacts on non-citizen and non-English speaking populations (Berkowitz 2008).

In addition to concerns about where CSO outlets are located and which communities bear the burden of CSOs as utilities plan CSO reduction projects, the financing of CD compliance can also perpetuate inequity (Recchie et al. 2019). Detroit implemented a “user pays” financing structure to rely on local users in the system to pay for CSO control projects versus spreading the cost more regionally. However, the combined system is in the oldest parts of the city where rents are lower. Newer developments in wealthier suburbs were built with separated sewer systems financed with public funds. Therefore, financing CD compliance on a “user pays” basis makes the residents with the least ability to pay cover the costs of decades of underinvestment. In Detroit, the unintended consequence of the “user pays” infrastructure cost allocation was the increase of existing regional inequities and magnification of the impacts of historical housing discrimination (Recchie et al. 2019).

Public Engagement: The literature identified steps to help ameliorate the inequitable impacts of CSOs. CSO reduction programs take a long time to plan, design, and build, so near-term action is necessary to address ESJ concerns. Adding clearly visible, non-technical signage translated into multiple languages about the location of outfalls and the dangers of CSO exposure could reduce the health risks to residents while working towards CD compliance (Berkowitz 2008). CSO control can also offer an opportunity for economic development. Recchie and colleagues suggested that local governments seek to contract GSI design and installation with local businesses. Directing public spending to local businesses would keep the rates collected in low-income communities for CSO reduction recirculating within those communities (Recchie et al. 2019).

Literature Review Theme 3: Decision-making under uncertainty

Six papers presented strategies to support decision-making for infrastructure investments even with large uncertainties about future conditions. The project team identified the following themes:

- Use scenarios to explore multiple potential futures
- Use of “regret” to discriminate between options instead of “optimality”
- Evaluate the change in performance of each strategy as the climate changes over time and consider time to design and implement each strategy.

A key challenge when planning for climate change is making decisions when key input parameters are uncertain. The Agency Interviews section discussed how changing rainfall patterns have introduced uncertainty in facility sizing decisions for WTD. In addition, CSO facility sizing is dependent on population growth and redevelopment patterns, both of which can change over time.

Scenario usage: Models are often used to simulate potential future scenarios. WTD has used models for many years to plan, design, and optimize CSO facilities. Three articles discussed how creating scenarios can help explore multiple potential futures (van Vuuren et al. 2011, Fischbach et al. 2017, Casal-Campos et al. 2015). Development scenarios can range from comparing projected growth with double projected growth (Fischbach et al. 2017) to selecting model simulation parameters based on variability in growth patterns and regulations (Casal-Campos et al. 2015).

In addition, many of the reviewed papers included a “do nothing” scenario to capture the impacts of increased rainfall due to climate change and population growth on existing systems absent of any investment in CSO control. Analyzing a “do nothing” scenario may reveal that the cost of doing nothing is more expensive than proposed capital projects. Use of scenarios helps frame performance variability of proposed solutions when using parameter sets that span the range of possible outcomes.

Even with the use of scenarios, additional decision-support tools are often necessary to interpret model results and reduce uncertainty for sizing decisions. Organizing results and synthesizing them into easy-to-understand charts helps participants understand the trade-offs involved in decisions. The article summaries include examples of useful data visualization techniques (see especially Casal-Campos et al. 2015 and Sadr et al. 2020).

Regret minimization: Pivoting away from the “optimal” solution to using “regret minimization” may enable decision-making even when design targets are uncertain (Casal-Campos et al. 2015, Fischbach et al. 2017, Sadr et al. 2020). Choosing low-regret strategies is similar to a standard multi-criteria analysis. However, with regret minimization, the goal is avoiding a mistaken strategy versus selecting the most optimal strategy. “Regret” is measured as the difference between the performance of a given adaptation strategy and the performance of the best strategy tested (for a given set of development and climate conditions).

Change in performance over time: Strategies to reduce CSO overflows can take a long time to design, build, and/or implement. Different strategies have different timelines and could change in performance over time. Examining change in performance over time can be useful in discussing strategies. Sadr et al. (2020) posed the question, given how long it will take to build something, will it be useful before its “sell by” date? In that paper, the authors evaluated change in “regret” as climate changes over time, not just at an arbitrary endpoint (Sadr et al. 2020).

A similar concept, but with much more explicit modeling of the ideal times to switch between strategies, is the Dynamic Adaptive Policy Pathways approach developed in the Netherlands (deltares.nl/en/adaptive-pathways/). Townsville, Australia, formalized the idea of a “sell by” date in its coastal hazard adaptation plan by using Monte Carlo simulations to identify the most cost-effective year of implementation for a wide variety of adaptation options. The “sell by” date is a useful metric for large capital projects that can have prolonged design and public consultation timelines (Harper et al. 2013). These articles highlight the challenges of managing a CSO system, including planning, constructing, operating, and funding a combined sewer system while meeting regulatory requirements and incorporating uncertainty from climate change.

4.0 Next Steps

The agency interviews provided information as to what peer agencies may or may not be doing about climate change impacts on CSO and wastewater systems. Similarly, the literature review provided current study for topics regarding real-world performance of GSI, ESJ considerations for combined sewer systems, and decision-making in the face of uncertainty. WTD will use the documented literature review and agency interviews to inform internal policy and program decision-making.

Additionally, WTD will use information learned in this project to inform the long-term planning process and develop adaptation and resiliency strategies using most current climate data and modeling tools. Furthermore, WTD will continue to develop recommendations for guidance on how to incorporate climate change data into the planning, design, construction and operations and maintenance of WTD's existing and future facilities.

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Appendix A

Questions asked at Agency Interviews

Agency Interview Re: Climate Change and CSOs for King County Wastewater Treatment Division

Date of Interview:	
Agency:	
Person Interviewed:	**Role:**
Interviewer:	

Objective

King County Wastewater Treatment Division is trying to understand how their peer agencies are predicting and incorporating impacts of climate change in their wastewater capital planning and design efforts, particularly around combined sewer overflows (CSOs) and has retained Murraysmith to assist them. King County is particularly interested in developing climate change resiliency in CSO control infrastructure as they work to comply with their consent decree. Your agency was identified as a leader in this space and a potential resource for this project, so we'd like to learn more about your work. In particular, we are interested in the following topics:

- Quantifying the impacts of climate change and managing uncertainty
- CSO reduction plans
- Financing and financial assumptions
- Regulatory environment and flexibility
- Social Justice (ESJ) and Public Involvement

We have detailed our questions in this document. Some of these questions may be easily answered via email and others we'd like to arrange a time to discuss over the phone. We wanted to share all the questions with you in advance of our discussion and have separated the questions into two sections to facilitate the interview, however we are happy to adjust the questions if you have a preference. Please email your written answers via email to Amina Kedir at amkedir@kingcounty.gov a few days before the scheduled interview if possible. If you have any questions, please feel free to contact Amina by email or phone (206. 263. 8656). We will share our results with you when our survey is complete.

Advance questions that can be answered via email

Quantifying the impacts of climate change and managing uncertainty

- How do you consider and evaluate impacts from Climate Change when planning, designing for, and analyzing CSO infrastructure? What tools, data and approaches do you use for predicting and quantifying climate impacts on facility sizing or facility performance? (Examples include modeling and monitoring) How far out into the future are you modeling or estimating? Any references or published materials are appreciated.

CSO Reduction Plans

- What types of solutions have you historically implemented in your collection and conveyance system to help control CSOs (i.e., storage, real time controls, treatment capacity, GSI)? Have climate change considerations impacted this approach?
- Does your agency have authority to manage stormwater? If not, who do you coordinate with to manage stormwater? What strategies do you use to manage stormwater? What tools do you use to assess their effectiveness? Are they working?
- Please describe any climate change response plans specific to wastewater infrastructure. What is the status of your implementation, and have you seen any results?

Financing and financial assumptions

- When considering what capital investments your agency will commit to for your capital plan, what financial considerations have you considered to accommodate impacts from climate change?

Regulatory environment and flexibility

- Are the agency's state and local regulatory entities integrating climate impact considerations into requirements/regulations? If yes, please describe how the impacts are considered and any additional detail associated planning or implementing any requirements?
- What are the regulatory performance criteria or standards that CSO facilities are required to meet for control (e.g., Washington state requires no more than 1 CSO/year per CSO outfall on a 20-year rolling average)? How do you track and assess compliance with your regulatory standard (design storm, rolling average in long-term simulation model, etc.)?

Discussion questions for phone interview

Quantifying the impacts of climate change and managing uncertainty

- How is the agency assessing and addressing uncertainties and risk associated with climate change? How are you quantifying risk and uncertainty?
- Has the agency experienced any compliance issues related to changing rainfall patterns or other climate impacts such as controlled CSO outfalls falling out of compliance? If so, what has been considered to manage those issues in the future?

CSO Reduction Plans

- How do you build consensus inside your agency around infrastructure sizing decisions between planning, engineering, and management? What decision tools or processes do you use to make decisions on facility sizing using your climate impacts data?

Financing and financial assumptions

- How are you currently funding CSO compliance and have you considered any additional sources of funding? Have you explored “green bonds” or other innovative financing vehicles (e.g., DC water uses 100-year bonds for financing tunnels) for infrastructure in general or infrastructure impacted by climate change? (For DC water only) How have the 100-year bonds worked out? Any lessons learned?

Regulatory environment and flexibility

- Have you implemented any of the following approaches: adaptive management, project phasing, or vulnerability assessments to incorporate changing conditions over time? If so, please describe the approaches used, and were these approaches effective and why? If you use adaptive management, please describe how you do it over time and how adaptive management is integrated in your agreement with regulatory agencies?

Social justice (ESJ) and public involvement

- What have been the responses/reactions from elected officials, customers, and other stakeholders to your approach to incorporating impacts of climate change to CSO mitigation?
- How are communities of color and their input explicitly engaged in the planning process? How are you supporting communities disproportionately impacted by pollution or CSOs?

Appendix B

Synopses of Selected Papers

Table 1. Selected papers for literature review. Papers are listed in alphabetical order by theme with a brief synopsis of each paper.

		Effectiveness of Green Stormwater Infrastructure (GSI)
J. Chen et al.	**2019**	**Evaluation of the effectiveness of green infrastructure on hydrology and water quality in a combined sewer overflow community**
Hydrologic model of Peoria, IL. Explored ability of different GSI strategies to control CSOs with current rainfall. Found that strategies using the public right-of-way only would not work as well as those with both public and private GSI installations. Only a small proportion of the study watershed was suitable for GSI, which may impact the relative effectiveness of different strategies.		
X. Hou et al.	**2020**	**Is the sponge city construction sufficiently adaptable for the future stormwater management under climate change?**
The "Sponge City Construction Systematization Program" is a Chinese urban stormwater management initiative that emphasizes "green" strategies to retain or reuse precipitation. This article modeled the effectiveness of one pilot design and quantified the increased CSO risk under climate change. The authors found the proposed projects would keep urban flooding problems from getting worse with climate change, but—even if the design works exactly as planned—would only match the poor performance of the current system.		
L. Locatelli et al.	**2020**	**Socio-Economic Assessment of Green Infrastructure for Climate Change Adaptation in the Context of Urban Drainage Planning**
Modeling study of two Spanish cities examining multiple potential benefits of GSI under future rainfall conditions. Proposed GSI differed for each city, based on local feasibility according to local stakeholders. Barcelona proposed green roofs and bioretention cells spread throughout the city and 10 detention basins with a total volume of nearly 40 million gallons in the upstream fringe of the city. Badalona proposed a mix of green roofs, permeable pavements, and infiltration trenches. The authors found that the biggest benefit of GSI was different for each city. Also found that hydrological performance of GSI can be a significant source of uncertainty.		
M. J. Pennino et al.	**2016**	**Watershed-scale impacts of stormwater green infrastructure on hydrology, nutrient fluxes, and combined sewer overflows in the mid-Atlantic region**
Desktop study looking at cumulative watershed-level impacts of GSI as actually built and maintained. A wide array of GSI types have been installed in the study area, but performance was not analyzed by GSI type. No relationship between CSO volume and percent of the watershed served by GSI was detected. The more general hydrology analysis found a statistically significant relationship between percent GSI and both peak runoff and frequency of flows greater than 3-month average, but the magnitude of the effect is small. The percentage of watershed served by GSI ranged from 0 to 60 but even the significant relationships have a shallow slope (specifically, going from 10 percent of watershed tributary to GSI up to 60 percent tributary to GSI doesn't reduce peak volume very much), and the investigators were not able to show reduction in flashiness in individual watersheds as more GSI were built over time.		

W. Shuster and L. Rhea	**2013**	**Catchment-scale hydrologic implications of parcel-level stormwater management (Ohio USA)**
		An experimental study of one catchment in suburban Cincinnati, divided into control and experimental sub-watersheds. Measured watershed-level impacts of voluntary rain barrel/rain garden installation on detention and runoff volume. Despite the careful experimental setup, the investigators were unable to show a statistically significant impact of the GSI installation with their original statistical approach. A revised, more complex, analysis showed a significant relationship between GSI treatment and discharge, but the magnitude was weak. There are several reasons why Shuster and Rhea's results might not generalize to King County: the study area was single family residential with a low percent impervious (14 percent), the only GSI trialed was collecting runoff directly from roofs, and finally, it is unclear what percentage of the basin is tributary to a GSI. It is possible that the experimental treatment was not extreme enough to show the reductions in runoff volume that might be expected in more urbanized basins.
H. Tavakol-Davani et al.	**2016**	**How does climate change affect combined sewer overflow in a system benefiting from rainwater harvesting systems?**
		Modeling study of Toledo, OH. Modeled the impact of climate change on CSO volumes with and without a single GSI type (cisterns used for toilet flushing). The authors considered two future climate scenarios, chosen to bracket the range of possible changes to precipitation. They found that climate change might cause up to a 12–18 percent increase in the frequency, volume, and duration of CSOs, under the most severe impact scenario in the near future but that 200-gallon cisterns installed on 50 percent of buildings would not only mitigate that increase, but decrease number, duration, and volume of CSOs below baseline.
R. Wang et al.	**2013**	**Consequential Environmental and Economic Life Cycle Assessment of Green and Gray Stormwater Infrastructures for Combined Sewer Systems**
		Modeling study using a "typical" urban watershed in the northeastern U.S. to conduct holistic cost-benefit analysis of different types of gray and green infrastructure. Environmental benefits defined in terms of water quality (nutrients and heavy metal concentrations). Improvements in the pollution levels of CSOs are considered but not reductions in CSOs per se. Cost defined in kilogram oil equivalent; this study is focused on sustainability and infrastructure's *contributions to* climate change, not just dollar costs of responding to climate change. The authors conclude that adding GSI is more costly (from a resource use perspective) than just separating stormwater, but if separated stormwater would need to be treated for water quality concerns, GSI is cost effective.
		Equity Impacts
J. D. Berkowitz	**2008**	**Into the Mystic. Combined sewer overflows (CSOs) and community demographics in the Mystic River Watershed: An environmental equity analysis**
		Looks at location of CSOs through an equity lens, describing how certain communities are disproportionately burdened by the effects of CSOs. The author uses the Mystic River Watershed in Massachusetts as a case study.
A. Recchie et al.	**2019**	**Water Equity and Security in Detroit's Water & Sewer District**
		Looks at the environmental injustices of Detroit, Michigan's, water and sewage systems. Analyzes the equity and social justice impacts of funding structures in addition to the direct impacts of living near a CSO outfall. Offers seven recommendations that can be pursued to remove structural barriers to region-wide water security and its environmental and public health benefits.

		Decision-Making under Uncertainty
A. Casal-Campos et al.	**2015**	**An Integrated Environmental Assessment of Green and Gray Infrastructure Strategies for Robust Decision Making**
		Uses four narrative development scenarios ("Markets," "Innovation," "Austerity," "Lifestyles") to compare "regret" expected by choosing a green or gray infrastructure approach. "Regret" is measured as the difference between the performance of a given adaptation strategy and the performance of the best strategy tested (for a given set of development and climate conditions). Choosing low-regret strategies is similar to a standard multi-criteria analysis, except instead of trying to select the optimal strategy, you are trying to avoid a mistaken one. The authors use a simple graphic to combine results for multiple infrastructure options, multiple performance metrics and multiple development scenarios to clearly show the tradeoffs embodied in different infrastructure options and the consequences of failing to decide (the "do nothing" scenario).
J. R. Fischbach et al.	**2017**	**Robust Stormwater Management in the Pittsburgh Region**
		RAND study that showed that Pittsburgh's rainfall is already up to 15% higher than the 'typical year" used for planning by ALCOSAN. Climate change is not a future consideration for Pittsburgh but is already here. None of the adaptation options considered fully eliminates sewer overflows, but there are some "low regret" options that could be good starting points and the cost-effectiveness of GSI improved as rainfall intensity increased, suggesting that GSI may be a more resilient option than a gray-only approach. The authors used "Robust Decision Making" to develop both the scenarios and the strategies tested. This is a resource intensive approach that required substantial commitments of staff time and expertise from all stakeholder agencies in the region but allows for more options to be evaluated before the final set of scenarios and strategies are selected.
I. M. Kourtis and V. A. Tsihrintzis	**2021**	**Adaptation of urban drainage networks to climate change: A review**
		Review and meta-analysis of prior work. This article reviews 32 case studies from around the world, focused on adaptation techniques of urban drainage network to climate change. Proposes a new approach to climate change adaptation based on results of meta-analysis, which is most relevant to academic research projects and would be difficult to apply at a utility scale. Does provide useful information on which modeling platforms are most used and how uncertainty is addressed.
S. M. K. Sadr et al.	**2020**	**Strategic planning of the integrated urban wastewater system using adaptation pathways**
		Extension of work by Casal-Campos et al. Same modeling setup but uses 5-year increments instead of one "future climate" to examine how relative performance of CSO reduction strategies changes over time. Condenses these detailed results into clear graphics that show the change in performance of each adaptation strategy over time. These graphics are used to identify a "sell by date" for each strategy.
B. Szelag et al.	**2021**	**Simulation of the number of storm overflows considering changes in precipitation dynamics and the urbanization of the catchment area: A probabilistic approach**
		Modeling study seeking to predict CSOs without needing a detailed hydraulic model. Used a Polish city as an example and compared their logistic regression model to results from a conventional hydrodynamic model. Their objective was to use a simpler model to examine the impact of climate change combined with changes to imperviousness (specifically, interaction of climate change and land development) and develop concept plans cheaply. Also interested in understanding the impact of uncertainty in rainfall predictions on estimated probability of overflows, using a Monte Carlo approach to simulate rainfall.

D. P. van Vuuren et al.	2011	The use of scenarios as the basis for combined assessment of climate change mitigation and adaptation

An examination of how to use scenarios to explore potential future emissions, and thus what climate change impacts might be expected by a given planning horizon. Model ensemble used has been superseded, so results are not directly transferrable.