EPA/600/R-07/033A

A Screening Assessment of the Potential Impacts of Climate Change on Combined Sewer Overflow (CSO) Mitigation in the Great Lakes and New England Regions

External Review Draft Report

U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment
Global Change Research Program

John Furlow, Thomas Johnson, Britta Bierwagen

and

ICF International
1725 Eye St, NW
Washington, DC 20006

J. Randall Freed, Jeremy Sharfenberg, Sarah Shapiro

September, 2006

PREFACE

The Environmental Protection Agency's Global Change Research Program (GCRP) is an assessment-oriented program within the Office of Research and Development that focuses on assessing how potential changes in climate and other global environmental stressors may impact water quality, air quality, aquatic ecosystems, and human health in the United States. The Program's focus on water quality is consistent with the *Research Strategy* of the U.S. Climate Change Research Program - the federal umbrella organization for climate change science in the U.S. government - and is responsive to EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. The GCRP's water quality assessments also address an important research gap. In the 2001 *National Assessment of the Potential Consequences of Climate Change in the United States* (Gleick and Adams, 2000), water quality was addressed only in the context of the health risks associated with contaminated drinking water. A comprehensive assessment of the potential impacts of global change on water quality was not included.

Since 1998, the National Center for Environmental Assessment's office of the GCRP has assessed the consequences of global change on water quality. Through its assessment projects, this Program has provided timely scientific information to stakeholders and policy makers to support them as they decide whether and how to respond to the risks and opportunities presented by global change. This report assesses the potential impacts of climate change on combined sewer overflow mitigation efforts in New England and the Great Lakes Region. Water treatment infrastructure was identified as a priority concern because water treatment is an essential service necessary to protect public health and ecosystems. Investments in water treatment infrastructure are also capital-intensive, long-term in nature, and irreversible in the short- to medium term. Today's decisions will thus influence the ability of treatment facilities to accommodate changes in climate for many years into the future.

The report is a screening level analysis intended to determine the scope and magnitude of global change impacts rather than a detailed assessment of specific impacts and adaptation measures. Together with a companion report addressing the potential effects of climate change on treatment costs at wastewater treatment facilities in the Great Lakes Region, this report fulfills a GCRP 2006 Annual Performance Measure to complete *"two external review draft reports detailing the possible impacts of global change on combined sewer overflows in key regions, and the possible effects of climate change and variability on operations and management of publicly operated treatment works (wastewater facilities) for OW and EPA Regions."*

Peter Preuss, Ph.D.
Director
National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Research Program

Acknowledgements

We are very grateful for the many thoughtful comments and suggestions made by members of staff from the EPA Global Change Research Program and ICF International in developing and conducting this work. In particular, we thank Susan Julius from the EPA Global Change Research Program. We are also very grateful for the many excellent comments and suggestions provided by four peer reviewers of this report: Christopher Impellitteri (US EPA, ORD/NRMRL/WSWRD/WQMB), Mohammed Billah (US EPA, OW/WPD), Donald Brown (US EPA, ORD/NRMRL/WSWRD/WQMB), and Tom Faber (US EPA, Region 1, OEME).

Executive Summary

Climate is a major factor influencing the amount, timing, and quality of water available meet human needs (Gleick 2000). During the last century, much of the U.S. experienced increased ambient air temperatures and altered precipitation patterns (NAST 2000). Projections of future climate suggest these trends are likely to continue, and potentially accelerate during the next century. Future changes in climate could thus impact water quality management.

Streamflow is strongly influenced by precipitation intensity and frequency, air temperature, and various natural and anthropogenic factors affecting watershed hydrologic processes. Projected impacts of climate change on streamflow include changes in both the total amount and temporal variability of flow. Climate change is expected to increase the proportion of rainfall occurring in high intensity events (US GCRP 2000), resulting in increased stormwater runoff and high flow events. At the same time, a shift towards more intense storms could also decrease infiltration and groundwater recharge, resulting in reduced low flow periods between events.

Combined sewer systems (CSSs) collect and co-treat storm water and municipal wastewater. During high intensity rainfall events, the capacity of CSSs can be exceeded resulting in the discharge of untreated storm water and wastewater directly into receiving streams. These combined sewer overflow events (CSOs) can result in high concentrations of microbial pathogens, biochemical oxygen demand, suspended solids, and other pollutants in receiving waters.

The EPA's Office of Water has established the CSO Control Policy, which requires CSS communities to implement various mitigation measures as a component of the National Pollutant Discharge Elimination System (NPDES) permitting process. Mitigation measures are typically engineered to handle storm or flow events of a given intensity, duration, and frequency, and there is an implicit assumption that precipitation and hydrology are constant over time. The rules guiding the mitigation measures are also based in part on an understanding of how precipitation intensity affects sewer performance. In many regions, climate change could increase the frequency of high intensity rainfall events, resulting in an increased risk of CSO events and associated water quality impairment.

The objective of this research was to characterize the nature and extent of climate change impacts on CSO mitigation efforts in the Great Lakes Region (GLR) and New England Region (NER). The study examined the extent to which CSO long-term control plans may be under-designed if planners assume that past precipitation conditions are representative of future conditions. The primary areas of focus were on potential changes related to CSO frequency and design characteristics of mitigation efforts in response to climate change.

The two regions of the United States that were selected for study, the GLR and the NER, both have many CSSs, which are generally found in older cities and towns. The GLR and NER communities contain 182 and 135 CSSs, respectively. These communities account for nearly half of the 746 CSS communities in the United States (US EPA 2004).

The analysis compared historical and projected precipitation characteristics using data sets developed for the Vegetation-Ecosystem Modeling and Analysis Project (VEMAP). The Long Term Control Plan (LTCP) "Presumption Approach" (keyed to reducing CSO events to no more than four per year) was used as the mitigation target to assess impacts on CSOs. Using this mitigation target, a benchmark storm event was determined for each CSS community in each region, based on historical precipitation data from VEMAP.

Climate change is expected to affect the frequency and intensity of precipitation events. In the VEMAP analysis, two Global Circulation Models (GCMs) were used to project future conditions: the Hadley Centre Model and the Canadian Climate Centre Model. Both models provide projections on a grid with intervals of 1 degree latitude and longitude. The VEMAP GCM runs, although several years old, were used because (1) they provided a set of historical (weather station) data and projected (GCM) data on the same geographic footing (the 1-degree grid), (2) they had undergone considerable manipulation to convert monthly temperature and precipitation estimates (the raw output of the GCMs) to daily temperature and precipitation estimates, and (3) the data sets had been thoroughly peer reviewed. By comparing projected storm intensities against the benchmark storm event (based on historical storm intensities, the event that corresponding to four CSOs per year), the impacts of climate change were characterized in terms of (1) the extent to which systems may be “under-designed” and (2) the additional system capacity required to meet the mitigation target in the future.

The benchmarking analysis matched the locations of CSS communities with historical and projected precipitation datasets, using the portion of the VEMAP grid located in the GLR and NER. For the GLR, historical precipitation data for a 40-year period (1954-1993) were compared to projected precipitation data for a future 40-year period (2060-2099). For the NER, historical precipitation data for a 25-year period (1968-1993) were compared to projected precipitation data for a future 25-year period (2025-2050). The NER study was done subsequent to the GLR study, and the 25-year time period was selected for the NER to obtain information on climate change impacts that are more immediate in nature.

Results of this study suggest that for many communities in the GLR and a few in the NER, if engineers design CSO abatement measures based on historical precipitation characteristics, projected climate change will reduce the effectiveness of those measures in meeting the four event per year benchmark. In the GLR, systems designed to meet the benchmark based on past conditions would exceed the benchmark by an average (across communities and GCM projections) of 38 percent (i.e., about 1.5 excess overflows per year). Across all 182 communities, this translates to 273 events per year above the objectives of EPA’s LTCP.

In the NER, the analysis indicated inconsistent results with respect to the impacts of climate change on CSO characteristics due to disparate projections of the Hadley and Canadian models, and perhaps also due to the choice of a shorter, nearer-term time frame for the analysis. Under Canadian model projections, climate related changes will result in a 17 percent decrease in the annual frequency of CSO events on average, while the Hadley model predicts a 12 percent increase in the frequency of CSO events. Across all 135 communities, this translated to 94 fewer and 62 more events per year above the LTCP’s objectives under the Canadian and Hadley models, respectively.

In the GLR, the rainfall intensity corresponding to a recurrence interval of four events per year is projected to increase in the 2060-2099 period by an average of 10 percent. Holding event duration and infiltration constant, it can be assumed that the design capacity of a CSO storage system is linearly proportional to precipitation intensity; thus, the average design capacity in the GLR would need to increase by the same proportion. Considering that CSO mitigation projects can cost hundreds of millions of dollars, a 10 percent increase in cost to adapt to projected climate change is significant.

The results for the NER in the shorter term (2025-2050) were ambiguous, given the differences in direction in the results of the two GCMs.

Nonetheless, the results suggest that CSS planners are faced with an important decision on whether to invest additional money now to build in an additional margin of safety to ensure the mitigation effectiveness of CSO projects into the future, or to accept the risk of potentially significant costs of retrofitting/refurbishing CSO projects in the future to maintain mitigation effectiveness in the face of climate change. To the extent that climate change may involve more intense precipitation events, if the engineers designing the LTCPs base their calculations of system size (e.g., storage capacity) on *current* hydrology, in the future the mitigation actions taken as part of the LTCPs may not be able to meet the objective of no more than four CSO events annually. Given the improvements in the state-of-the-art in GCM modeling and analysis of empirical trends in precipitation, it would be worthwhile to develop tools based on more recent models and trend analysis to provide planners with heuristics for a margin of safety to address climate change.

Table of Contents

List of Tables

List of Figures

1 Introduction

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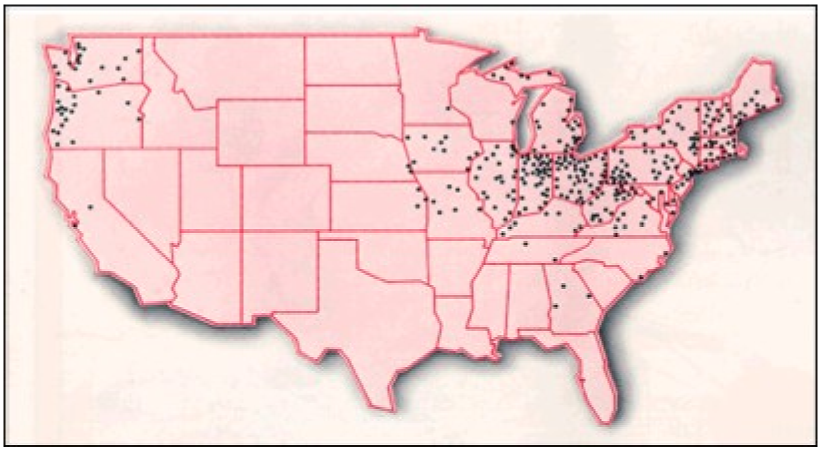
1.1 Combined Sewer Systems and Combined Sewer Overflows

A CSS collects storm water and sanitary wastewater in a common conveyance system and routes them to a treatment plant (US EPA 2004). The storm water component fluctuates with the weather; during rainfall events, the collection system and treatment plant must accommodate more volume due to runoff entering the system directly (street catch basins and gutter downspouts) or indirectly through groundwater infiltration. By design, when the volume of water in the collection pipes, storage facility, or at the treatment facility exceeds the system's capacity, excess water is discharged untreated at different points around the system into surface waters through CSO outfalls.

The water that is discharged to local rivers and streams during a CSO event is typically a mixture of raw sewage, other industrial wastewaters, and storm water. The sewage component is typically of greatest concern from a water quality standpoint due to bacterial and/or viral contamination. These discharges are known as CSOs. The term CSO refers to any discharge from a CSS prior to the treatment plant, but most occur in response to wet weather (US EPA 2004). EPA estimates that 850 billion gallons of overflow are discharged into the nation's waters each year.

According to EPA's 2004 Report to Congress on the Impacts and Control of CSOs and Sanitary Sewer Overflows (SSOs), there are 746 communities with combined systems and a total of 9,348 CSO outfalls identified and regulated by the NPDES permits (US EPA 2004). Combined sewer systems are found in 31 states and the District of Columbia, with the majority located in older cities found in the Great Lakes and New England Regions (see Figure 1).

Figure 1. Distribution of Combined Sewer Systems in the United States.
Source: US EPA web site, http://cfpub.epa.gov/npdes/cso/demo.cfm?program_id=5.



Construction of municipal sewer systems began in the 1880s. Prior to then, sewage was collected in cesspools and privy vaults (Burian et al. 2000). Populations were sparse enough that aesthetic concerns were not great, and the health risks were not well understood. As population densities grew during the 19th century, the need to remove waste became more critical. Cities had two goals in constructing sewers: first, as populations grew larger and more concentrated, privies and cesspools were no longer sanitary or aesthetically acceptable. Sewers were constructed to remove wastes from population areas. Second, heavy rains could render unpaved streets impassable, so storm waters needed to be quickly conveyed to rivers or lakes. The two designs that were common in this period were dedicated sanitary sewers and combined sewers to convey sewage and storm water. A third option, separate sanitary and storm sewers, was viewed as too costly for most communities (Burian et al. 2000).

Treatment was not a part of the process; the purpose was to convey the water away from the population and into some receiving body. The design choice depended on the needs of the community. In general, smaller communities opted for sanitary systems only. Larger cities used combined systems because they efficiently and effectively removed both storm and wastewater (US EPA 2004). In some cases, a combined system was chosen because storm water would flush the sewage out of the system and into receiving waters (Burian et al. 2000;Schladweiler 2005). At the turn of the twentieth century, these systems resulted in significant health benefits within the cities they served; there were however, to be consequences with respect to water quality in the receiving water bodies.

As the first sewer systems were being built, CSSs were a dramatic improvement over cesspools and open sewers. However, as populations grew, impacts of discharges into receiving waters grew as well. Now, of the 850 billion gallons discharged annually, 75 percent is discharged into rivers, streams, or creeks; 13 percent into unclassified or other waters such as canals; 10 percent into oceans, bays, or estuaries; and 2 percent into ponds, lakes, or reservoirs (US EPA 2004). CSOs result mainly from two different events associated with CSSs: (1) insufficient conveyance capacity within a portion of the sewer system and resultant surcharging and overflow through manholes or designed outfalls and (2) insufficient capacity at the water treatment plant. In the latter case the excess combined sewage must bypass the facility and be discharged at a specified outfall. This effluent is often given primary treatment before discharging.

CSOs pose a threat to water quality and human health. The pollutants found in CSOs include microbial pathogens, suspended solids, nutrients, toxics, and debris. Pollutant concentrations vary from place to place and storm to storm, but they can be high enough to cause violations of water quality standards. It is common for local rivers and streams to be considered dangerous to human health after heavy rains due to CSO pollution. It is difficult to attribute the violation of water quality standards exclusively to CSO discharges, because CSOs occur during storm events when some of the same pollutants are washed directly into waterbodies by storm water runoff.

Despite the difficulty of attributing causality to particular sources, EPA has compared data on CSO locations with data on 305(b) assessed water segments and 303(d) impaired waters in 19 states.[1] The study found that of a total of 59,335 assessed segments, 25 percent were impaired. For 733 segments that were within a mile downstream of a CSO outfall, 75 percent were impaired. Though it is difficult to determine how much of the impairment is due to the CSO, the high percentage of impairment associated with CSOs suggests some correlation (US EPA 2004). CSOs should be considered as a potential source of pollution during Total Maximum Daily Load (TMDL) development, and in some communities substantial load reductions have been assigned to CSOs as a result of the TMDL process (US EPA 2004).

CSOs also pose risks to human health and the environment. Humans can become sick by drinking contaminated water, eating contaminated shellfish, or coming in direct contact with contaminated water. The most common symptoms of pathogenic illness are diarrhea and nausea, but respiratory and other problems can occur as well. Toxics present in CSO discharges include metals and synthetic organic chemicals. Less is known about the risks of biologically active chemicals such as antibiotics, hormones, and steroids (US EPA 2004).

[1] 305(b) and 303(d) are references to sections of the Clean Water Act that mandate assessment of water bodies, and identification of impaired waters, respectively.

1.2 CSO Controls

Efforts to manage the risks of CSOs have evolved over several decades. Following the passage of the Clean Water Act in 1972, publicly owned wastewater treatment works (POTWs) were required to incorporate secondary treatment into their wastewater treatment processes. Effluent from the treatment plant had to be treated, but it was unclear how CSOs – discharges from the collection system, not the treatment plant – would be treated by the law. A 1980 court ruling declared that CSO outfalls did not have to be subjected to the secondary treatment required of discharges from a POTW. However, the discharges do fall under the National Pollutant Discharge Elimination System (NPDES) permit program (US EPA 2004). Under NPDES, all facilities which discharge pollutants from any point source into waters of the United States are required to obtain a permit. The permit holder must provide treatment based on technology accessible to all permittees in a particular industrial category (US EPA 2006).

In 1989, EPA issued the National CSO Control Strategy, which encouraged states to develop statewide permitting strategies to ensure that all CSSs were subject to a discharge permit. The strategy also recommended six minimum measures for controlling CSOs. As the control strategy was being implemented, environmental groups pushed for further action against CSOs, while many municipalities also called for greater clarity and a national approach (US EPA 2004). In 1994 EPA published the CSO Control Policy to establish objectives for CSS communities in order to reduce the environmental impacts of CSOs. Four key elements of the CSO Control Policy are meant to enable communities to cost effectively reduce overflows and meet the objectives of the Clean Water Act:

1. Provide clear levels of control that would be presumed to meet appropriate health and environmental objectives;
2. Provide sufficient flexibility to municipalities, especially financially disadvantaged communities, to consider the site-specific nature of CSOs and to determine the most cost effective means of reducing pollutants and meeting Clean Water Act objectives and requirements;
3. Allow a phased approach to implementation of CSO controls considering a community's financial capability; and,
4. Provide for review and revision, as appropriate, of water quality standards and their implementation procedures when developing CSO control plans to reflect the site-specific wet weather impacts of CSOs.

1.2.1 Nine Minimum Controls and Long Term Control Plans

The national CSO Control Policy also requires communities to implement nine minimum controls (referred to as NMC) and to develop a Long Term Control Plan (LTCP) to reduce the frequency and adverse impact of CSOs. The NMC are expected to maximize the effectiveness of existing systems. Among the controls are properly operating and maintaining the system; maximizing the flow to the POTW from the collection system; eliminating overflows during dry weather; and notifying the public of the occurrence and impacts of overflows. In addition to implementing the NMC, communities are expected to develop LTCPs that will ultimately result in compliance with the requirements of the Clean Water Act. The LTCPs are meant to provide communities with as much flexibility as possible in meeting the requirements.

The development and implementation of LTCPs are in various stages of completion, but all of the 746 communities that have CSSs must develop plans to comply with the CSO Control Policy. Permit holders designing modifications to their systems generally base their plans on historical weather data. The infrastructure investments made to implement LTCPs are expected to have life expectancies of several decades, and the costs will be considerable. There is no comprehensive source of individual municipal expenditures for CSO control because there are multiple funding sources for CSO projects. However, EPA compiled expenditures to date for 48 communities, roughly 6 percent of the nation's total. Those expenditures totaled $6 billion and ranged from $134,000 to $2.2 billion per community. EPA estimates that the capital costs of future CSO control over the next 20 years will exceed $50 billion (US EPA 2004).

1.2.2 CSO Control Policy Mitigation Requirements

The EPA's CSO Control Policy allows for three basic approaches to be taken in order to meet CSO mitigation requirements. First, a system may allow no more than four overflows per year (though the permitting authority may allow an additional two). Second, a system may eliminate or capture at least 85 percent by volume of the combined sewage collected in the system during a precipitation event. These first two approaches are considered to be "presumptive" in nature. Finally, the system may eliminate or remove no less than the mass of the pollutants identified as causing the water quality impairment for the volume that would be eliminated or captured by the 85 percent approach (US EPA 1994). The demonstration approach allows communities to demonstrate that their system, though not meeting the criteria of the presumption approach, is adequate to enable receiving waters to meet water quality standards and protect designated uses (US EPA 2004).

Given the number of communities working to develop and implement LTCPs, the costs associated with CSO control, and the weather's influence on overflow events, it is important to assess the potential impact of climate change on the robustness of LTCPs 25 to 40 years from now. To the extent that climate change may involve more intense precipitation events, if the engineers designing the LTCPs base their calculations of system size (e.g., storage capacity) on *current* hydrology, in the future the mitigation actions taken as part of the LTCPs may not be able to meet the objective of no more than four CSO events annually.

1.3 Climate Change and Impacts on the Hydrologic Cycle

Streamflow is strongly influenced by precipitation intensity and frequency, air temperature, and various natural and anthropogenic factors affecting watershed hydrologic processes. Projected changes in climate are thus likely to have a significant impact on the amount and seasonal variability of streamflow.

Climate change is expected to increase the proportion of rainfall occurring in high intensity events (US GCRP 2000). This will tend to increase stormwater runoff during events, resulting in increased high flow events without necessarily increasing the amount of water available. A shift towards more intense storms will also decrease infiltration and groundwater recharge. Low flow periods occur when there is little or no precipitation, and streamflow is supplied by groundwater. If a higher proportion of total precipitation is delivered in intense events, unless total precipitation increases significantly, low flow periods between events will thus likely decline.

The Intergovernmental Panel on Climate Change (IPCC) has reported that over the past century there has been a likely increase in the frequency of intense precipitation events in the mid-high latitudes of North America (Houghton et al. 2001). Recent observations and long term projections suggest that climate change will significantly influence the volume of storm water runoff and result in increased high-flow stream conditions (Watt et al. 2003). This has an important influence on water quality. Extreme precipitation events tend to be correlated to poorest water quality – due to runoff pollution and channel scouring during high flows – and are a significant stress on aquatic ecosystems.

1.4 Objectives of this Research

This study sought to characterize the nature and extent of climate change impacts on the effectiveness of CSO mitigation efforts in the Great Lakes and New England Regions, assuming that mitigation will involve infrastructure that is designed based on historical precipitation records. The study focuses on LTCP implementation, and uses a case study approach to examine the extent to which CSO long-term control plans may be under-designed if planners assume that past precipitation conditions are representative of future conditions. A limited, informal survey of EPA regional staff involved in CSO implementation in the GLR and NER indicated that the most common approach in the LTCPs was the presumption approach of controlling and providing a minimum level of treatment to all but four overflow events per year. The study was designed to analyze whether precipitation patterns in the future might result in more – or fewer – CSO events (with respect to the target of four per year) and what the potential increase in design capacity might be to adapt mitigation infrastructure to climate change.

The research questions to be evaluated were:

1. If CSSs meet the EPA's CSO Control Policy "presumption approach" of four events per year based on *historical* precipitation, what will be the potential change in CSO event frequency in the future as a result of climate change?
2. What would be the incremental change in the design capacity of mitigation measures that would be needed to meet the presumption approach of four CSO events per year under the projected precipitation regimes?

An improved understanding of the potential impacts of climate change on CSOs is important because the occurrence and mitigation of CSO events is highly sensitive to climate, is one of the highest-priority programs at the state and federal level, and will involve significant investment in wastewater treatment. These characteristics have been identified as important criteria to help focus decision support resources on activities that will have the greatest benefit towards adapting to climate change (e.g., Purkey et al. in press; Freed and Sussman in press). In addition, CSSs are typically managed by public agencies through decision-making processes that can be influenced by EPA, and are the subject of strategic analysis at the Agency due to the large gap in funds available versus funds needed for treatment system improvements. Thus, this study also addressed the question of how climate change could influence the costs of complying with CSO requirements. The Great Lakes (GLR) and New England (NER) Regions were selected as the focus of this study because of the large number of CSSs in these areas, and because of EPA GCRP's previous work with stakeholders in these regions as part of the regional assessment program.

2 Methods

The assessment methodology compares historical and future precipitation characteristics in the Great Lakes and New England Regions using a benchmarking approach. The LTCP presumption approach of reducing CSO events to no more than four per year was used as the mitigation target. Using this mitigation target, a historical benchmark event was determined against which projected precipitation events could be compared. Historical and projected precipitation data were obtained from the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP), which uses projections of future precipitation from two global circulation models (GCMs): the Hadley Centre Model and the Canadian Climate Centre Model. CSS communities in the Great Lakes and New England Regions were mapped to VEMAP data points. The impacts of future climate change on CSO frequency and mitigation requirements were then estimated by comparing the benchmark event intensity representing four CSOs per year based on historical versus projected future precipitation data. The following sections provide a more detailed discussion of the assessment methodology.

2.1 CSS Selection

A national list of CSS locations was obtained from a 2004 EPA Report to Congress (US EPA 2004). Latitude and longitude were determined for each CSS by cross referencing NPDES permit numbers with location information in the Permit Compliance System (PCS), or based on city location. CSS communities within the Great Lakes and New England Regions were selected as described in the following sections.

2.1.1 Great Lakes Region

The Great Lakes are part of the largest freshwater system in the world, and are bounded by eight states: Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, and New York. (US EPA 2004; GLRA 2006). 182 CSS communities with active CSO permits were identified within the Great Lakes watershed; Table 1 presents a breakdown of CSS communities within the Great Lakes watershed by state.

Table 1. GLR CSS Communities by State

State	Number of CSS Communities
Minnesota	3
Wisconsin	2
Michigan	46
Illinois	34
New York	23
Indiana	24
Pennsylvania	3
Ohio	47
Total	**182**

2.1.2 New England Region

The New England Region was defined to include seven states: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, and New York (excluding NYC). 135 active CSO permits were identified in the New England Region (US EPA 2004). Table 2 shows the breakdown of CSS communities by state in the New England Region.

Table 2. New England Region CSS Communities by State

State	Number of CSS Communities
Connecticut	5
Maine	39
Massachusetts	22
New Hampshire	6
New York (upstate)	53
Rhode Island	3
Vermont	7
Total	**135**

2.2 CSO Benchmarking Approach

There is considerable heterogeneity among CSSs in terms of baseline water quality conditions, progress toward complying with EPA's national CSO Control Policy, and the site-specific approaches that will be used to reduce the frequency of CSO events. It is required by EPA, however, that all CSS communities develop a LTCP that includes an evaluation of alternatives to meet CWA requirements by using either the "presumption approach" or the "demonstration approach". One of the most common design objectives of LTCPs is to achieve EPA's presumption approach standard of no more than an average of four CSO events per year. Under this criterion, a CSO event is defined as any overflow from a CSS that does not receive the minimum level of treatment defined in the CSO Control Policy.

2.2.1 Presumption Approach Basis

In this study it was assumed that each CSO community in the GLR and NER will design their system to achieve an average of four CSO events per year (i.e., the presumption approach threshold), and will base their design on historical precipitation data. Given this standard, the "benchmark" storm event that will need to be captured to meet the four-event per year average was determined. By characterizing daily precipitation data in this way, a straightforward means of comparing historical and projected precipitation characteristics was created. Historical precipitation data were compared with precipitation projections from the two global circulation models (GCMs) used in the VEMAP analysis.

2.2.2 VEMAP data and GCMs

Historical and projected daily precipitation data were obtained from the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP), administered by the National Center for Atmospheric Research (NCAR) data group. Projected future precipitation datasets were created using two global circulation models (GCMs): the Canadian Centre for Climate Modeling and Analysis and the Hadley Centre models created in 1995. The GCM outputs were converted to daily projections based on a modified version of the stochastic weather generator WGEN, (Richardson and Wright 1984).[2] The GCM outputs and the daily scaling incorporate many limitations and a considerable degree of uncertainty, as described exhaustively in the VEMAP documentation (http://www.cgd.ucar.edu/vemap/index.html). Although VEMAP simulations are several years old and subject to limitations, the VEMAP results were deemed to be suitable for a screening level assessment determining the potential magnitude and direction of climate change impacts.

2.2.3 Benchmarking Analysis

The locations of CSS communities were matched with historical and projected precipitation datasets from the VEMAP grid located in the GLR and NER. For each region, the CSS communities were assigned to the nearest U.S. VEMAP site for which data were available. A historical dataset compiled by VEMAP was selected for each CSS community, based on the grid point to which each was mapped.

For the GLR, historical precipitation data for a 40-year period (1954-1993) were compared to projected precipitation data for a future 40-year period (2060-2099). For the NER, historical precipitation data for a 25-year period (1968-1993) were compared to projected precipitation data for a future 25-year period (2025-2050). The NER study was done subsequent to the GLR study, and the 25-year time period starting in 2025 was selected to provide information on climate change impacts that are more immediate in nature.

The historical and projected precipitation data were analyzed based on both a 1-day and a 4-day moving average. The moving average approach was used to allow the temporal characteristics of storage in CSO mitigation measures to be simulated, i.e., the time lag between onset of precipitation and peak flows (and demand for storage) within a CSS. The choice of 1-day and 4-day timeframes provided lower and upper bounds on both (a) time of travel within the sewershed or area draining to the treatment plant (from “upstream” boundaries to the treatment plant) and (b) the effects of multiple rain events in quick succession.

The precipitation intensity value that corresponds to the theoretical benchmark event was determined based on the assumption that CSSs in the GLR and NER will design their systems to meet the four-event per year standard based on historical precipitation intensity. This served as the historical benchmark event for each system. In theory there will be only four rain events (in an average year) that exceed this benchmark if a CSS community is meeting the objectives of the CSO Control Policy. In the case of the GLR, the benchmark event was identified as the 160th largest precipitation intensity values (in inches/day) in each of the 40-year aggregated 1-day and 4-day average precipitation datasets (4 events per year * 40 years of data). For the NER, the benchmark event was identified as the 100th largest precipitation intensity values in each of the 25-year aggregated 1-day and 4-day precipitation datasets (4 events per year * 25 years of data).

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[2] WGEN is a weather simulation model developed at the USDA-ARS Grassland, Soil and Water Research Laboratory that is used to scale down GCM outputs to a daily time-step. The model uses a probability function (first-order Markov chain) where the chance of precipitation is conditioned on the wet or dry status of the previous day, and the intensity is based on a gamma distribution where small events occur more frequently than large events.

Note that in each region, this corresponds to the precipitation event (1-day or 4-day) with a recurrence interval of 3 months, or a probability of occurrence of 0.011 on any given day. This approach was used to identify the precipitation event intensity that would have to be mitigated to meet the CSO Control Policy goal of an average of four events per year over the selected time periods.

The future four-event per year benchmark event was determined for each VEMAP grid location using both the Canadian and Hadley models. Each VEMAP grid location was also weighted according to the number of CSSs represented by that grid location. By evaluating the projected precipitation data in this manner, the theoretical number of excess events and the incremental increase in the benchmark event intensity (as an indicator of required CSO storage capacity) was determined.

3 Results and Discussion

3.1 Changes in CSO Event Frequency

The results of this analysis provide an estimate of the percent change in the frequency of CSO events in the future under climate change relative to the four-event per year threshold based on historical data. It is assumed that municipalities will design mitigation measures (e.g., a deep storage tunnel) to meet this standard, and if historical precipitation is used as the design standard, the effectiveness of those mitigation measures could be reduced in the future. The basic metric presented in this section is the percent change in CSO event frequency relative to the four-event per year presumption approach benchmark event. For example, a 50 percent change in CSO event frequency would equate to two additional CSO events per year, on average, or a total of six CSO events per year if the mitigation measures were designed using historical precipitation data.

3.1.1 Great Lakes Region

Results show that relative to an assumed four event per year benchmark event, the average annual CSO frequency in the GLR would increase between 13 percent (Canadian model, 1-day averaging period) and 70 percent (Hadley Centre model, 4-day averaging period). In other words, the average number of CSO events per year would increase to 4.5 using the lowest projected average change, and 7.1 using the highest average projected change (see Table 3).

Table 3. Weighted Average Percent Change in CSO Frequency in the Great Lakes Region, 2060-2099. The percent change is expressed relative to the four events/year standard, *e.g.*, a 50% change equals two additional CSO events/year.

Moving Average	Canadian	Hadley
1-Day	13.4 %	49.4 %
4-Day	18.8 %	70.0 %

Figure 2 shows the distribution of the percentage change in CSO frequency (number of communities) in the GLR based on a 1-day moving average of daily precipitation. The Hadley model projects an increase in precipitation intensity for all locations, while the Canadian model projects decreases at 10 of the communities (5 percent). Accordingly, based on the Canadian model, there are 10 communities that are projected to experience a decrease in CSO frequency of 10 to 0.1 percent. At the other end of the spectrum, the Hadley model predicts an 80 to 90 percent increase in CSO frequency for 10 communities. For these 10 CSS communities, this would mean an additional 32 CSO events per year, on average. Figure 3 shows a similar plot using the 4-day averaging period. These results generally indicate wider distributions and greater impacts (though for the Canadian model, there is an increase in the number of communities with fewer CSO events). Figure 34 shows the cumulative distribution for the Hadley and Canadian models for both averaging periods.

Figure 2. Percent Change in Frequency of CSO Events in the Great Lakes Region, 2060-2099 (1-Day)

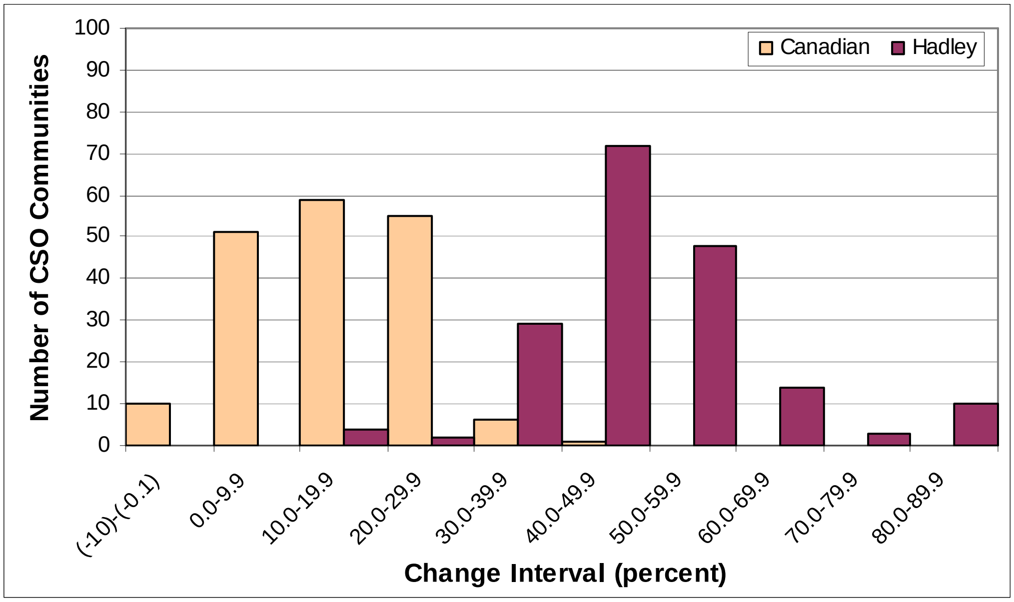


Figure 3. Percent Change in Frequency of CSO Events in the Great Lakes Region, 2060-2099 (4-Day)

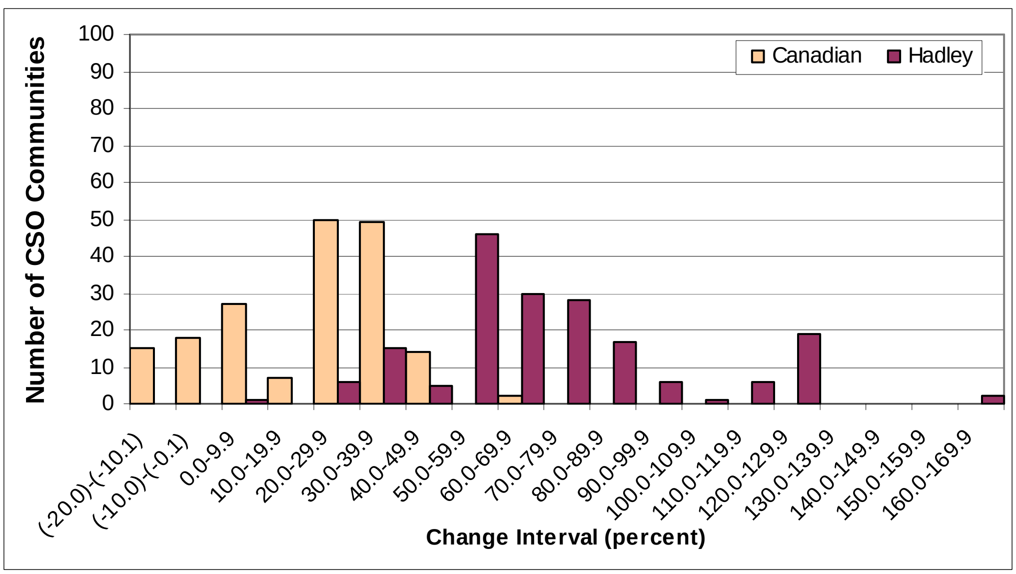
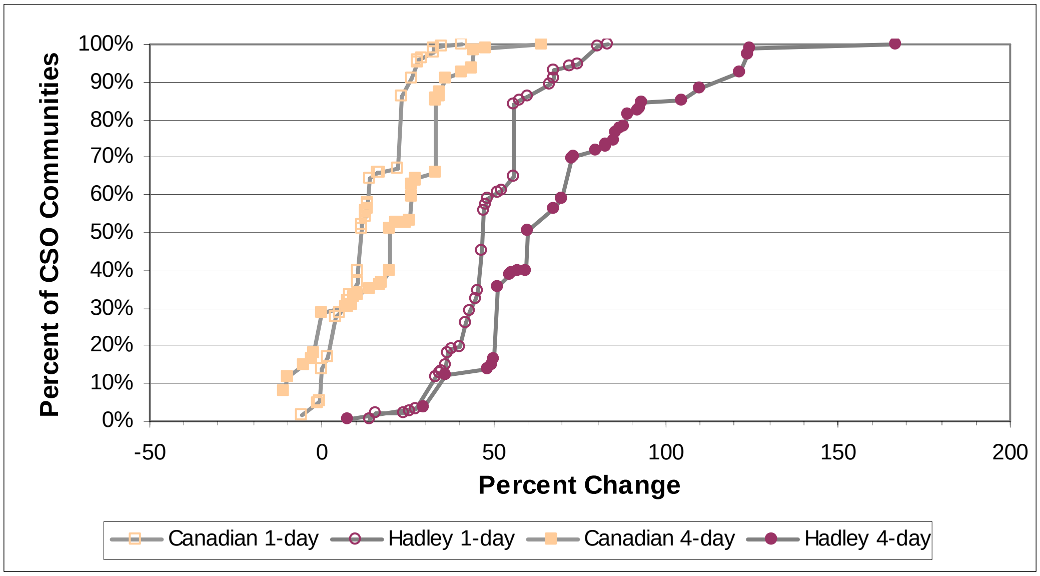


Figure 4. Cumulative Distribution of % Change in CSO Frequency in the Great Lakes Region, 2060-2099



3.1.2 New England Region

Results for the NER show that relative to an assumed four event per year benchmark, the average annual CSO frequency in the NER during the 2025-2050 period would change within a range of -24 and 14 percent (Table 4). In other words, the average number of CSO events per year would decrease to 3.0 using the lowest projected average change, and 4.6 using the highest average projected change.

Table 4. Weighted Average Percent Change in CSO Event Frequency in the New England Region, 2025-2050

Moving Average	Canadian	Hadley
1-Day	-10.4 %	8.8 %
4-Day	-24.5 %	14.4 %

Figure 5 shows the distribution of the percentage change in CSO frequency (number of communities) in the NER based on a 1-day moving average of daily precipitation. The Hadley model projects an increase in precipitation intensity for the majority of locations, while the Canadian model projects decreases for the majority of the communities. Based on the Canadian model, there are 10 communities that are projected to experience an increase in CSO frequency of more than 10 percent, 76 communities that will have less than a ±10 percent change, and 49 communities that are projected to experience a decrease in CSO frequency of more than -10 percent. Alternatively, the Hadley model predicts 48 communities to have an increase in CSO frequency of more than 10 percent, 64 communities with less than a ±10 percent change, and 23 communities with decreases in CSO frequency exceeding -10 percent.

Figure 6 shows a similar plot using the 4-day averaging data. As shown in Figure 7, the 4-day results generally indicate a greater decrease in frequency than the 1-day results based on the Canadian model. There is little difference in these distributions based on the Hadley model.

Figure 5. Percent Change in Frequency of CSO Events in the New England Region, 2025-2050 (1-Day)

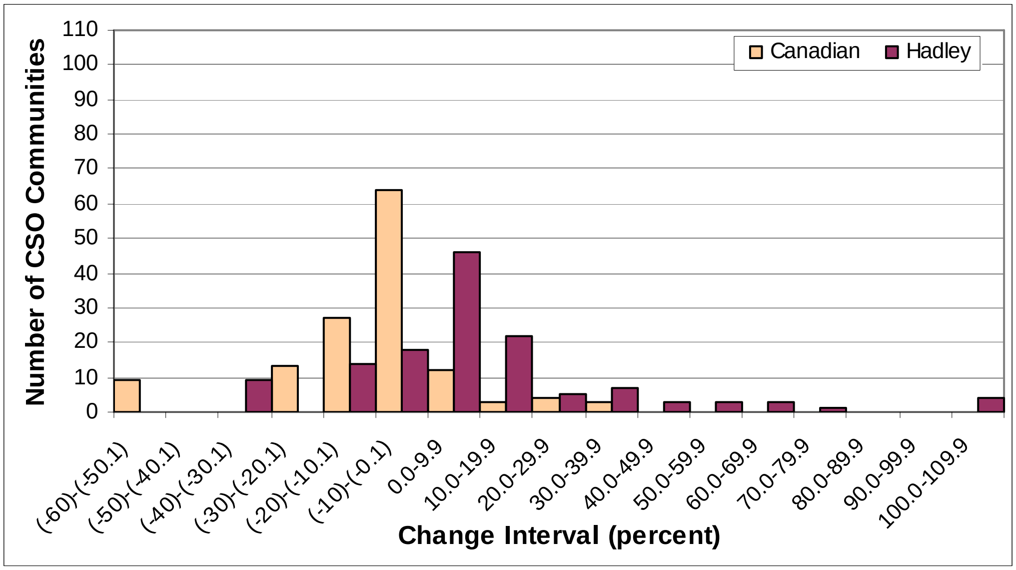


Figure 6. Percent Change in Frequency of CSO Events in the New England Region, 2025-2050 (4-Day)

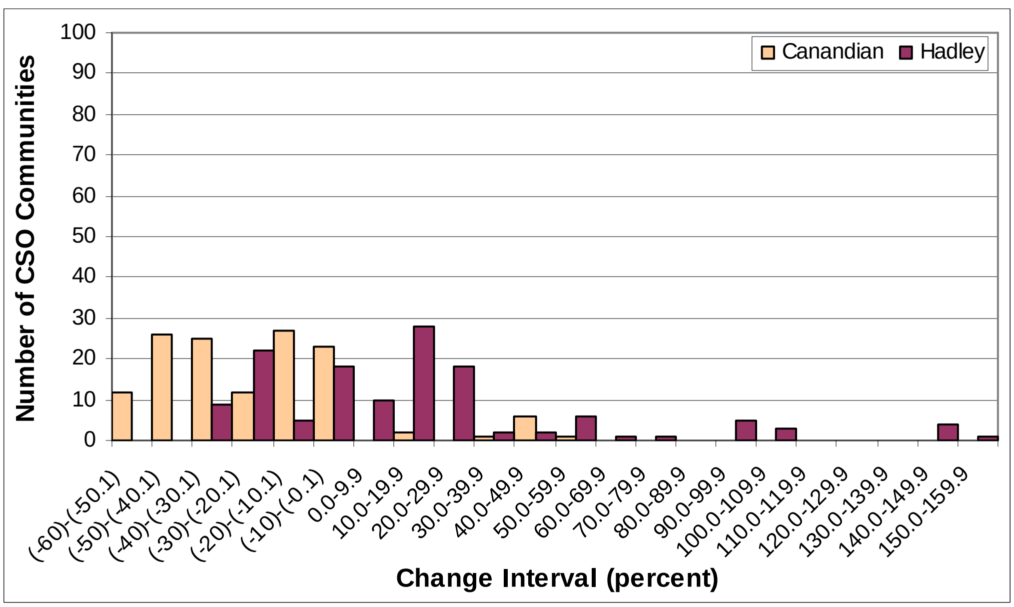
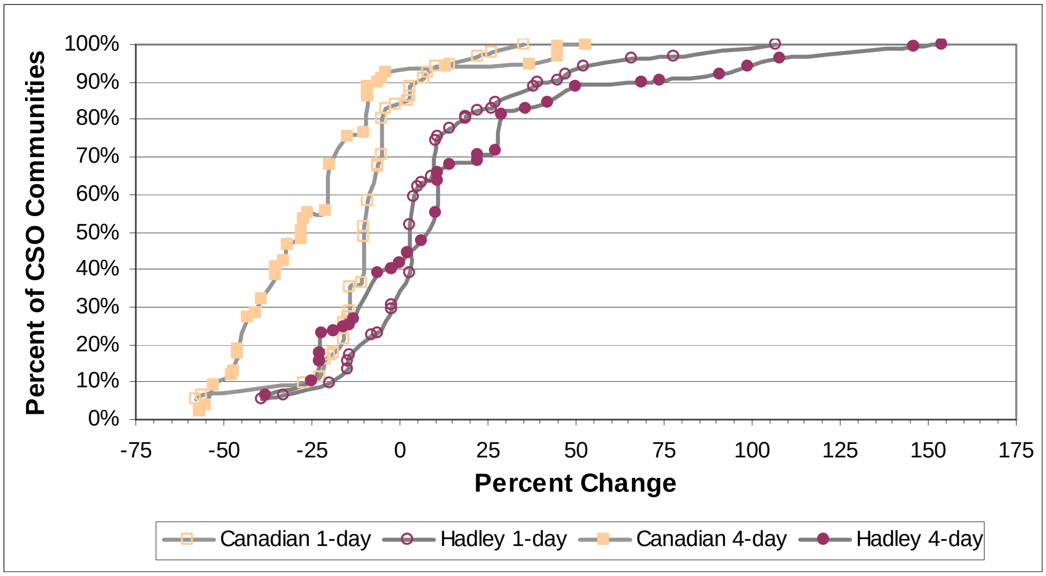


Figure 7. Cumulative Distribution of % Change in CSO Event Frequency in the New England Region, 2025-2050



3.2 CSO Benchmark Event Intensity

A second objective of this analysis was to estimate the projected rainfall event intensity that would need to be captured to meet the four-event per year threshold under future climate conditions. Event intensity values provide an indication of how CSO mitigation design parameters would need to be modified to account for future climate change. This information could be useful to municipalities interested in implementing CSO mitigation measures (e.g., a storage basin) that are robust to future changes in climate. The basic metric presented in this section is the percent change in future benchmark event intensity relative to the historical benchmark under the four-event per year presumption approach. In this case, a 10 percent increase in benchmark event intensity would imply that the design of the system would need to be sized for a roughly 10 percent larger storm to account for climate change. Although the relationship between precipitation event intensity and CSO volume generated is not perfectly linear, this analysis provides an approximation of the change in design capacity that would be needed to adapt to climate change. An evaluation of potential costs associated with increasing design capacity to adapt to climate change is also presented.

3.2.1 Great Lakes Region

The average rainfall intensity corresponding to a recurrence interval of 4 events per year in the GLR is projected to increase by between 5 and 16 percent (see Table 5).

Table 5. Average Percent Change in Benchmark Event Intensity in the Great Lakes Region, 2060-2099

Moving Average	Canadian	Hadley
1-Day	4.8 %	16.2 %
4-Day	5.1 %	14.9 %

Individual CSS communities in the GLR, however, are projected to have future reductions as well as increases in the CSO benchmark event intensity. Figure 8 shows the distribution of changes in CSO benchmark event intensity based on a 1-day moving average of daily precipitation. Based on the Canadian model, there are four communities that are projected to experience a decrease in CSO benchmark event intensity between -5 to -0.1 percent. At the other end of the spectrum, the Hadley model predicts a 25 to 29.9 percent increase in CSO benchmark intensity for two communities. Where an increase in rainfall benchmark event intensity is projected, the design capacity of a CSS storage system would need to increase in order to maintain the presumption approach standard of no more than four events per year. Where there is a projected decrease in benchmark event intensity, mitigation measures designed using historical precipitation characteristics would be more effective in reducing CSOs than their design objective.

Figure 9 shows the distribution of changes based on the 4-day averaging period. As with the change in event frequency, for the Canadian model, the distributions for the 4-day period are shifted to the right compared to those with the 1-day period. However, the distribution for the 4-day period is shifted to the left slightly for the Hadley model. Figure 10 presents the cumulative distributions of the 1-day and 4-day averaging periods for percent change in benchmark intensity under the Hadley and Canadian models.

Figure 8. Percent Change in CSO Benchmark Event Intensity in the Great Lakes Region 2060-2099 (1-Day)

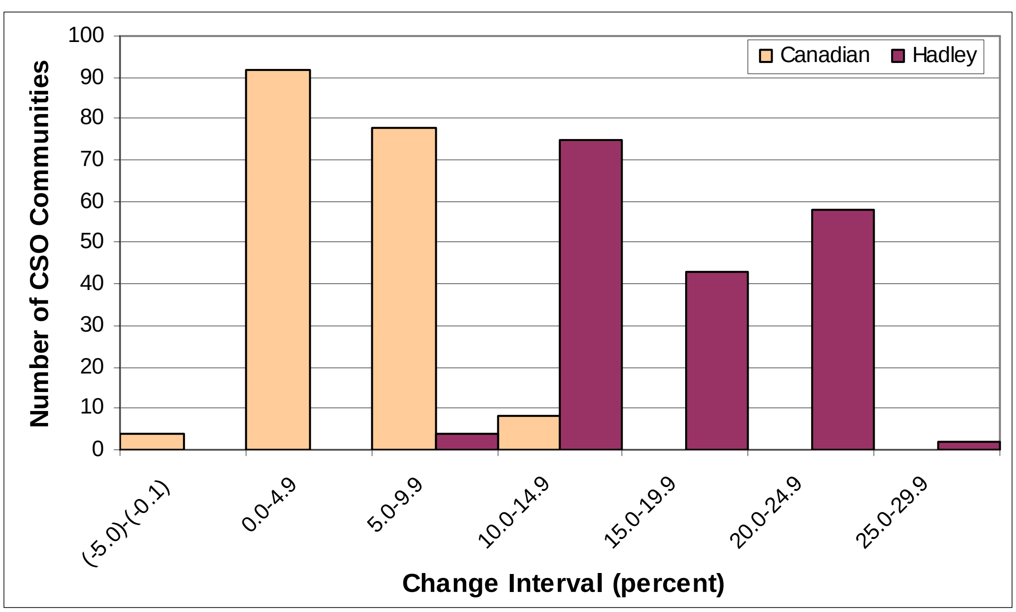


Figure 9. Percent Change in CSO Benchmark Event Intensity in the Great Lakes Region, 2060-2099 (4-Day)

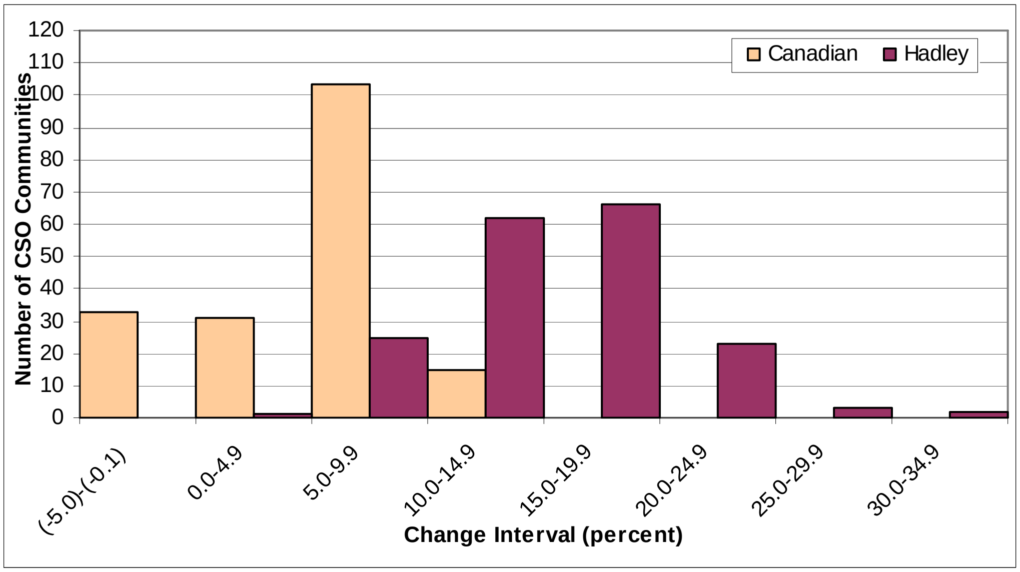
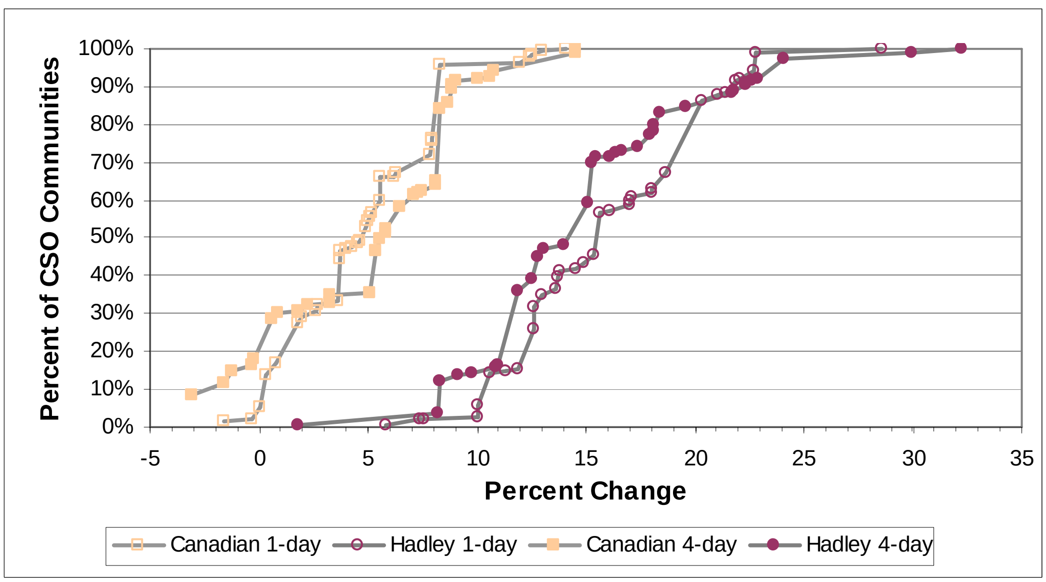


Figure 10. Cumulative Distribution of % Change in Benchmark Event Intensity in the Great Lakes Region, 2060-2099



3.2.2 New England Region

In the NER, the average rainfall benchmark intensity corresponding to a recurrence interval of four events per year is projected to change within the range of -6 to +3 percent (Table 6).

Table 6. Average Percent Change in Benchmark Event Intensity in the New England Region, 2025-2050

Moving Average	Canadian	Hadley
1-Day	-3.2 %	2.8 %
4-Day	-5.7 %	3.1 %

Some CSS communities are projected to have reductions, and others to have increases in the CSO benchmark event intensity due to differences in the GCM model projections. Figure 11 shows the distribution of changes in CSO benchmark intensity based on a 1-day moving average of daily precipitation. Based on the Canadian model, only three communities are projected to experience an increase in CSO benchmark event intensity exceeding 10 percent, while the Hadley model projections imply that 21 communities would have increases in event intensity exceeding 10 percent.

Figure 12 shows the distribution for the 4-day averaging period. As with the change in frequency of events exceeding the historical benchmark, the distributions for the 4-day period under the Canadian model are shifted slightly to the left, indicating a decrease compared to those with the 1-day period. Figure 12 presents the cumulative distributions of the 1-day and 4-day averaging periods for percent change in benchmark event intensity under the Hadley and Canadian models.

Figure 11. Percent Change in CSO Benchmark Intensity in the New England Region, 2025-2050 (1-Day)

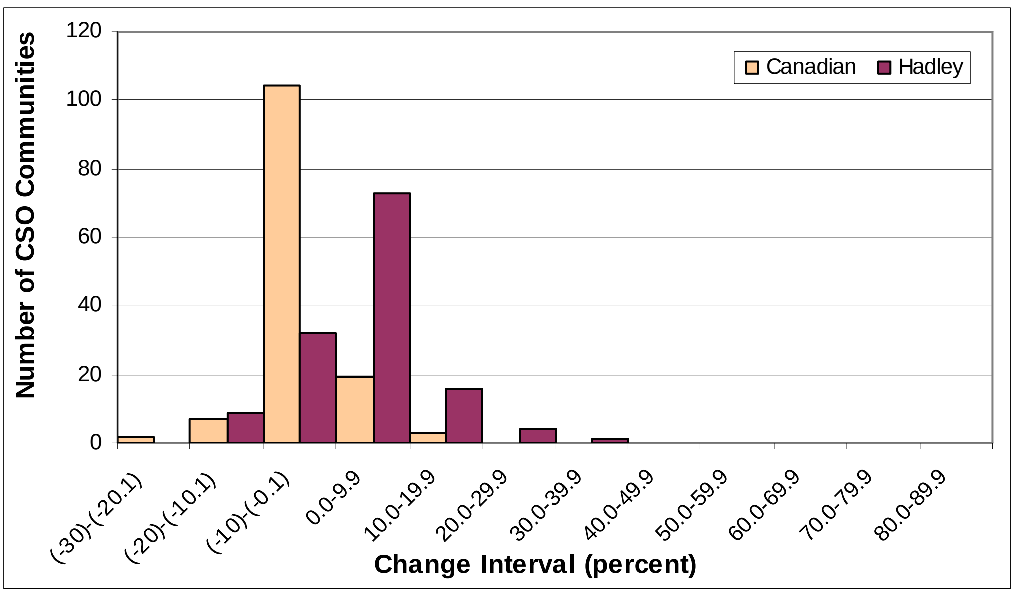


Figure 12. Percent Change in CSO Benchmark Intensity in the New England Region, 2025-2050 (4-Day)

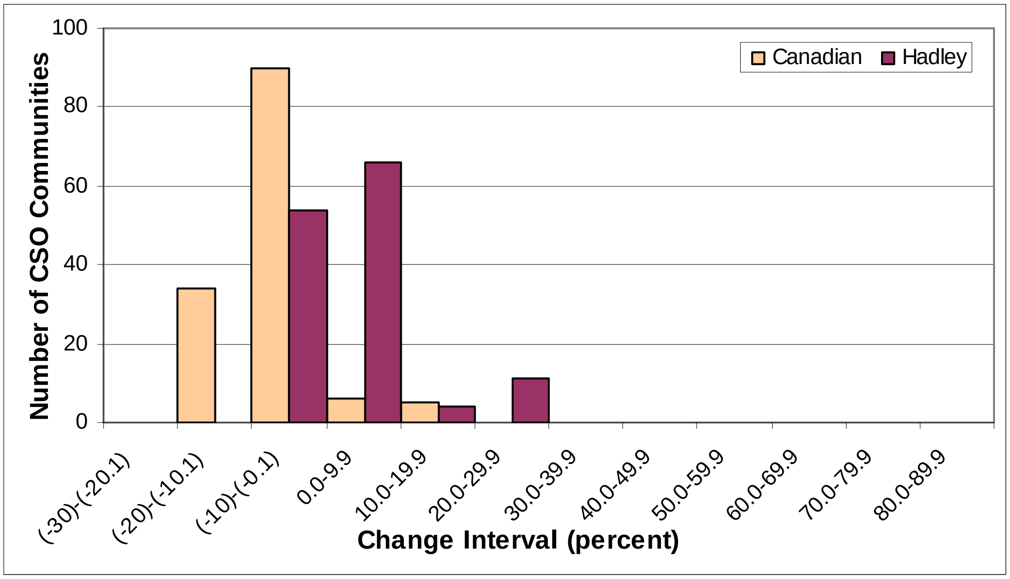
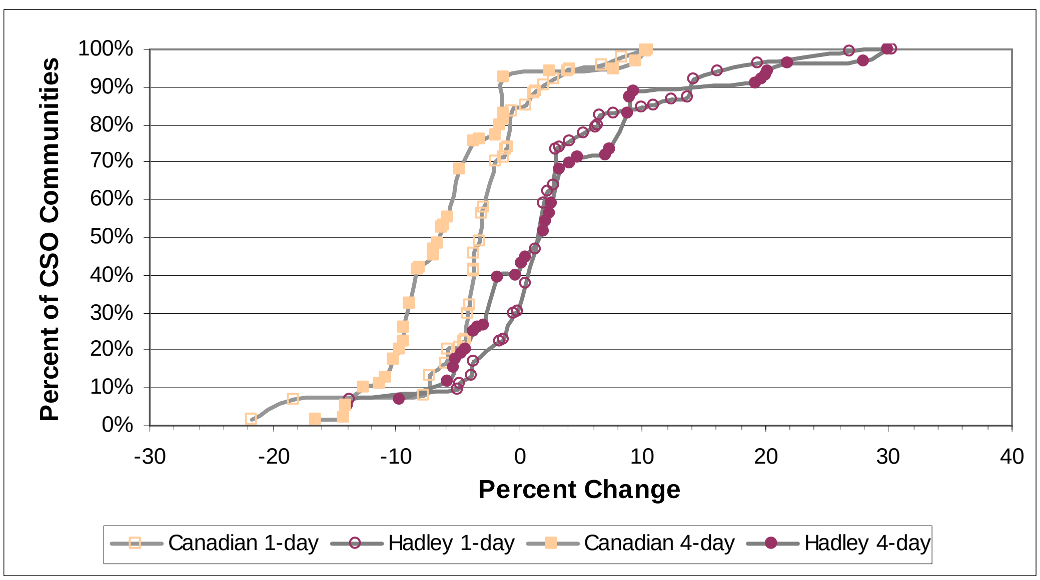


Figure 13. Cumulative Distribution of % Change in Benchmark Intensity in the New England Region, 2025-2050



3.2.3 Costs of Adaptation — Increased Mitigation Design Capacity

It is ultimately of concern to water managers how to adapt to future climatic conditions. In considering how system capacity might have to change to accommodate the altered weather patterns of the future, several considerations must be kept in mind. CSO volume is a function of many factors, including sewer system conveyance and storage capacity, wastewater treatment plant capacity, and inflow and infiltration rates. To provide a rough bounding analysis of the costs of adaptation, two runoff scaling factors were used to estimate the change in runoff compared with a change in precipitation intensity. Chiew et al. (1993) suggest that the percent change in runoff is about twice the percent change in precipitation in wet and temperate areas. The United Nations Food and Agriculture Organization (FAO) suggests that runoff increases at half the rate of the increase in precipitation (FAO 1991). We used these marginal runoff production rates as lower and upper bounds on the change in runoff per unit change in precipitation.[3]

A future decrease in the intensity of the benchmark storm would improve the effectiveness of control measures at reducing CSO frequency and volume. Therefore, four examples were selected from the NER in which both models project a significant increase in the magnitude of the benchmark storm for the 1-day average. Table 7 shows the projected change in runoff for these examples using the Chiew and FAO scaling factors.

Table 7. Projected Change in Runoff Volume, 1-day Averaging Period

VEMAP Location	% Change, Canadian	0.5x scaling	2x scaling	% Change, Hadley	0.5x scaling	2x scaling
Warren Co., PA*	6.8	3.4	13.6	30.3	15.2	60.6
Allegany Co., NY	4.0	2.0	8.0	19.3	9.7	38.6
St. Lawrence Co., NY	10.3	5.2	20.6	5.3	2.7	10.6
Wyoming Co., NY	8.3	4.2	16.6	16.2	8.1	32.3

* VEMAP point on the NY border representing one CSS community in upstate NY.

A CSS engineer or planner designing a system to accommodate increased runoff would have to weigh the increased system costs against the risks of more intense storm events. The most common approach to controlling greater runoff is to increase storage capacity. Capital cost functions reported by EPA for constructing storm water mitigation systems suggest that costs have a scaling factor, with respect to flow, on the order of 0.7 (US EPA 2002a). As an example, Wyoming County, NY, is projected to have an increase in runoff of between 4 percent and 32 percent, using the 1-day Hadley model projections and the two runoff scaling factors. This suggests a cost increase of between 3 and 21 percent, depending on the scaling factor.

The actual costs for a CSS would vary depending on any economies of scale related to estimated construction costs for mitigation measures associated with Long Term Control Plans based on historical precipitation data. Planners would have to consider the cost of constructing now versus the cost of doing so, if necessary, in the future, as well as the cost of borrowing additional money now for construction versus the cost of borrowing in the future.

[3] Note that these estimates may be conservative; recent research conducted in the United Kingdom estimates that a 20 percent increase in rainfall due to climate change would require a seven-fold increase in CSO storage volume to maintain performance (Wilkinson and Balmforth 2004), implying a rate of 35% increase in runoff per 1% increase in precipitation.

To the extent that planners modify their LTCPs to account for an additional margin of safety to account for climate change, it would require additional capital investment. This would place additional burden on already limited funds for CSO mitigation projects at all levels of government. As is indicated in the 2000 Clean Water Needs Survey, which was based on LTCPs that had been submitted as of 2000, CSO mitigation efforts in the surveyed communities are projected to require $50 billion over the next 20 years (US EPA 2003). This is in addition to other drinking water and wastewater treatment needs that are in the tens of billions of dollars.

3.3 Regional and Temporal Variance

This analysis is strongly influenced by variability in climate change projections in time and space. In the case of the long-term (2060-2099) projections for the Great Lakes, the Canadian and Hadley GCMs both predict an increase in CSO event frequency (with respect to a historical benchmark) and the benchmark for the 4-event per year storm. However, with the near-term New England Region projections, the models produced inconsistent results; the Hadley GCM predicted an increase in CSO frequency and the benchmark event, and the Canadian GCM predicted a decrease in frequency and benchmark event.

This variability has important implications for how results should be interpreted. For example, based on the Canadian model, if control measures in the NER are designed based on historical precipitation characteristics, climate-related changes could result in a 17 percent decrease in CSO events per year across averaging periods, i.e., an increase in the effectiveness of mitigation measures. A similar analysis based on the Hadley model predicts a 12 percent increase in overflows. Across all 135 communities, this translates to 94 fewer and 62 more events per year above the control policy's objectives under the Canadian and Hadley models, respectively.

The contrasting GCM results found in the NER highlight the difficulty of making clear predictions for specific communities. The Canadian and Hadley models both project that region-wide in the NER, annual average precipitation will increase as of 2100 by about 10 and 25 percent, respectively, compared to 2000 levels. However, making projections over the shorter term, and downscaling both in space (regions to grid cells to communities) and time (monthly projections to daily values), the picture becomes more opaque.

Moreover, our methodology focused on values at the high end of the precipitation distribution – the 100th largest out of 9,130 values (25 years) for the NER and the 160th largest out of 14,600 values (40 years) for the GLR. The validity of these values is a function both of the validity of the GCM projections and the validity of the downscaling approach used to manipulate those projections. Most models are more valid in their estimation of central tendencies than in the tails of the output distribution, and to the extent that we are concerned here with the high-end tail, the results should be used with caution.

3.4 Limitations and Future Research

There are several limitations to consider when interpreting the results of this research. These limitations are related to the analytic framework and the data. These limitations, along with the screening-level findings, point to the potential for future research in this area.

3.4.1 Limitations

Key limitations include the following:

- *Presumption Approach* – The CSO Control Policy "Presumption Approach" standard of no more than four events per year is assumed to be the main objective of CSS managers, and increasing system storage is the primary mitigation measure used to meet this standard. In practice there are many site-specific issues that make development of long-term control plans very complicated, and not all planners choose to increase storage as their primary mitigation measure. Moreover, the Control Policy also allows use of a "demonstration approach" based on levels of effluent treatment and water quality standards of the receiving waterbody. Thus, the analysis takes a relatively simple approach to a very complex and heterogeneous system, and it lacks the technical robustness that would result from the use of sewer system models such as the Storm Water Management Model (SWMM).

- *Benchmarking* – Our analysis is based on a benchmarking comparison of historical and future daily precipitation based on weather observations and GCM projections. The statistical techniques used to determine benchmarks are often more sophisticated and complicated than the simple ranking technique used in this study, and may yield slightly different results. Moreover, the historical datasets used to establish storm intensity, duration, and frequency may go back further in time than the 25-year period used for the NER or the 40-year period used for the GLR. To the extent that there are underlying trends in precipitation[4] toward increasing intensity of storm events, using a thin temporal slice of the historical dataset tends to understate the difference between design objectives based on observed weather and future conditions.

- *General Circulation Models* – The GCM results EPA used (Canadian and Hadley) are projected on a monthly time step. They were then converted to daily projections based on the stochastic weather generator, WGEN. The initial GCM outputs and the daily scaling incorporate many limitations and a considerable degree of uncertainty, as described in section 3.3 and more exhaustively in the VEMAP documentation. All of those limitations and uncertainties apply directly to these results.

- *Averaging Period* –Although the analysis uses 1-day and 4-day averaging periods to bracket the effects of short intense storms and longer or multiple precipitation events in sequence, it is possible that by choosing shorter or longer periods the results would change. For example, the approach does not distinguish between intense precipitation "pop-up" events (e.g., a thunderstorm yielding two inches of rain in one hour) versus a steady rain that accumulates 2 inches over a full 24-hour period. These short but intense events can quickly overwhelm a CSS and result in an overflow or surcharged sewer condition. A higher resolution evaluation of hydraulic effects on an hourly time-step could only be analyzed using more sophisticated models (e.g., SWMM) and more fine-grained precipitation data.

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[4] For example, the observed 20th century values for annual precipitation were up to 25 percent greater than pre-20th century records for the eastern coastline of the NER, where many of the CSS communities are located (US EPA 2002b).

- *Snowmelt* – Our analysis of total daily precipitation does not distinguish between rain and snow. Snowfall is less likely than rainfall to result in elevated peak flows in a CSS at the time of the precipitation event, but snowmelt at a later date can have significant impacts on sewer flows, especially if the snowmelt occurs during a rain event. Moreover, rain on snow events can result in significant runoff, with virtually all of the rainfall converted to runoff, supplemented by melting snow. The evaluation of total daily precipitation does not differentiate between rain and snow. This is a significant limitation for our analyses of the GLR and NER, given the generally cold temperatures throughout these regions during the winter months.

3.4.2 Future Research

This study was intended as a screening level analysis to determine the potential scope and magnitude of global change impacts rather than a detailed assessment of specific impacts and adaptation measures. The results of this analysis suggest that more detailed analysis would be worthwhile in several areas:

- *Align Time Periods of Study* – Additional studies of this nature would benefit from an alignment of time periods selected for determining historical and projected climate conditions in different regions. Rerunning the CSO benchmarking analysis in the GLR and NER to extend and synchronize the time periods utilized for each might help resolve the disparate results presented in the study. If the longer-term results are consistent, it would help dispel some of the ambiguity evident in the near-term NER results.

- *Utilize More Recent Climate Models* – Newer GCM runs have become available since the VEMAP II dataset was created in the mid 1990s. There are also additional approaches for obtaining daily time-step projections through updated weather generators or GCMs that generate daily precipitation data. More up-to-date GCM results would reflect advances in the state of the science, and regional models (e.g., the UK Hadley Centre's PRECIS model) can provide better resolution on a regional basis.

- *Case Studies* – A smaller scale case study approach looking in detail at a few communities might provide more accurate data on system responses on an hourly basis. These case studies would likely involve the use of detailed sewershed runoff models such as SWMM. These models typically utilize continuous precipitation data, so a method for applying GCM outputs to modify historical continuous precipitation data would need to be created. This would provide a more robust analysis as event intensity on an hourly (or shorter time-step) basis for predicting CSO events would provide a more accurate basis than the daily precipitation data utilized for this screening study.

- *Determine Best Practices for Characterizing Design Storms* – One opportunity to provide useful guidance would be to establish a straightforward approach for modifying the Intensity-Duration-Frequency (IDF) curves and design storms commonly utilized for water resource engineering design and planning. To develop guidance, it would be useful to review (1) the current practices associated with creating IDF curves (e.g., how far back in the historical record, what statistical techniques are used) and (2) the extent to which recent trends in increasing storm intensity are already embedded in the IDF curves. One possible approach for modifying the way that design storms are calculated would be to utilize research examining trends in precipitation intensity over the last century. For example, research by Groisman et al. (2005) evaluated historical precipitation data for the US and determined that there were statistically significant trends indicating an increase in the intensity of the heavy (upper 5 percent of precipitation) events. Specifically, their research has found a 4.6 percent increase in event intensity per decade for the largest 5 percent of precipitation events; a 7.2 percent increase in event intensity per decade for the largest 1 percent of precipitation events; and a 14.1 percent increase in event intensity per decade for the largest 0.1 percent of precipitation events. Relationships like these could be used, along with assumptions on the design lifetime of CSSs, to provide adjustment factors for characterizing future storm intensity.

- *Margin of Safety* – Engineering design practices for CSS improvement projects typically include a margin of safety (MOS) to account for uncertainties. It would be informative to quantify the magnitude of the MOS typically utilized in CSO mitigation design. Moreover, it would provide a useful perspective to put the increase in design storm intensity (due to climate change) in the context of this margin of safety, as well as the potential for increase due to future changes in impervious surface, population, and other key design factors.

4 Conclusions

If climate change does indeed result in flashier precipitation events, changes in annual precipitation, earlier snow melt, and rising sea levels, water resource managers will need to adapt. Our analysis of long-term CSO mitigation in the GLR and NER indicates that if systems are designed based on historical precipitation characteristics, their efficacy in the future could be diminished due to climate-related changes. Specifically, it is likely that in the long term (2060-2099), CSO mitigation projects in the GLR designed using historical precipitation characteristics will experience an increase in the frequency of CSO events beyond their design capacity, and an increase in overflow volume discharged to receiving waterbodies. This could result in communities failing to meet the CSO mitigation goals established in their Long Term Control Plans, which in turn would result in the need for further modifications to the CSSs.

The results are inconsistent in the near term (2025-2050) in the NER, with different directionality in the results of the Hadley and Canadian models. The differences in projected precipitation changes between the GLR and NER demonstrates the regional texture of climate change, which translates into different decisions that planners in these regions may be making to protect wastewater treatment infrastructure.

The uncertainty associated with GCM projections (and especially the ambiguity in the near-term NER results) may deter CSS planners from considering climate change as a design factor in their long-term planning, given that CSO mitigation efforts are already highly complex and costly. However, it is important to consider this uncertainty in context:

- Planners already include other factors with similar uncertainty and long-term effects in their design. Although precipitation intensity is a key design factor, so is total impervious area, sewered area, population served, and per capita water demand. The design is quite sensitive to all of these factors, and each is subject to considerable uncertainty. Because the uncertainty is more familiar, however, planners are much more comfortable characterizing these factors with assumptions and estimates.

- Throughout much of the US, there is empirical evidence for a trend to increasing precipitation intensity (Karl and Knight 1998). Irrespective of the uncertainties in the GCM projections, it would be prudent to consider the likelihood of increasing storm intensity based on weather observations.

- It is possible that if more recent GCM results and downscaling routines were used, the results would be less ambiguous in terms of the direction of the effect.

A report published for the Toronto-Niagara Region Study on Atmospheric Change recommends that design storms utilized for storm water infrastructure construction be made 15 percent larger to account for expected climate change (Watt et al. 2003). In engineering terms, this recommendation essentially incorporates a margin of safety to specifically address climate change in the system design.

The threat of increased precipitation variability in the future could provide additional motivation for rigorous inflow and infiltration (I&I) mitigation programs that maximize the capacity of the existing CSS. By eliminating flow in sewers due to groundwater infiltration and runoff from gutter downspouts and sump pumps, additional capacity can be made available to reduce the frequency and severity of CSOs. Many municipalities already have aggressive I&I programs in place, and the potential for increased precipitation intensity in the future under climate change makes this mitigation option even more important.

States and local municipalities are already struggling to meet the demands of water resource management, and climate change would add an additional factor to the equation when weighing the price of clean water. The New York City Department of Environmental Protection estimates that the cost of increasing wet weather capture from 75 percent to 95 percent in response to climate change would cost $12-$40 billion for New York City alone(NYC DEP 2005).[5] This is a significant sum, and is close to the total cost of CSO mitigation efforts indicated for those communities responding to the 2000 Clean Water Needs Survey. As indicated by the research described in this report, it is clear that the costs of adapting CSO mitigation plans to manage the long-term risks associated with climate change could significantly increase funding requirements, exacerbating the existing gap between funding that is available and funding that is needed.

[5] The basis for the increase in percent CSO volume capture from 75 percent to 95 percent (and how it relates to the CSO Control Policy) was not explained by the NYC DEP in the reference cited.

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