Climate Change Vulnerability Analysis

Contract No. M03054P01

Prepared for

Milwaukee Metropolitan Sewerage District

Milwaukee, WI

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List of Abbreviations

CE-s10	End-of-Century, 10% Scenario
CE-s90	End-of-Century, 90% Scenario
cfs	cubic feet per second
CM-s10	Mid-Century, 10% Scenario
CM-s90	Mid-Century, 90% Scenario
CSO	Combined Sewer Overflow
CSSA	Combined Sewer Service Area
DC	Diversion Chamber
DFLOW	Design Flow Analysis
DS	Diversion Structure
EPA	United States Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FFS	Flow Forecasting System
gpad	gallons per acre per day
HQ	Headquarters
HSPF	Hydrologic Simulation Program – FORTRAN
H2S	Hydrogen Sulfide
IJC	International Joint Commission
IS	Intercepting Structure
ISS	Inline Storage System
MACRO	A flow accounting model used to perform long-term continuous simulations of the operation of the major components of the District conveyance, storage, and treatment system.
MCAMLIS	Milwaukee County Automated Mapping and Land Information System
MG	Million Gallons
mgd	million gallons per day
MIS	Metropolitan Interceptor Sewer
MMSD	Milwaukee Metropolitan Sewerage District
NOAA	National Oceanic and Atmospheric Administration
NSC	Near Surface Collector
NWSRS	Northwest Side Relief Sewer
PET	Potential evapotranspiration
Q1	First Quarter
Q2	Second Quarter
Q3	Third Quarter
Q4	Fourth Quarter
RAS	Return Activated Sludge
SEWRPC	Southeastern Wisconsin Regional Planning Commission
SSO	Sanitary Sewer Overflow
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
VRSSI	Volume Reserved for Separate Sewer Inflow
WDNR	Wisconsin Department of Natural Resources
WICCI	Wisconsin Initiative on Climate Change Impacts
WQI	Water Quality Initiative
WRF	Water Reclamation Facility
1B3	One-day average flow that occurs once every three years
4B3	Four-day average flow that occurs once every three years
7Q10	Seven-day average flow that occurs once every ten years

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Executive Summary

The Milwaukee Metropolitan Sewerage District (District) is undertaking a risk management approach to climate adaptation and consequently decided to undertake a climate change vulnerability analysis to assess how soon the impacts may materialize at a level to present a meaningful threat to existing and planned facilities and operations. This report provides an overview of the work that was completed for the climate change vulnerability analysis and the results and conclusions from this work.

The objectives of the analysis were to:

- Provide information for the District to make decisions on capital improvements and operational strategies in the face of changing hydrologic and climate conditions
- Assess how soon climate change impacts may materialize at a level to present a meaningful threat to existing or planned facilities and operations
- Quantify risk that will aid in developing adaption strategies

This report addresses these objectives by providing an:

- Overall assessment of potential vulnerabilities to District facilities and operations (Section 2)
- Evaluation of changes in the frequency and volume of combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) as a result of different climate change scenarios (Section 3)
- Evaluation of changes in high and low flows in two selected reaches of the District's jurisdictional watercourses within its service area as a result of different climate change scenarios (Section 4)
- Evaluation of changes in rainfall patterns as a result of climate change and the subsequent impacts to green infrastructure (Section 5)
- Identification of facilities at Jones Island Water Reclamation Facility (WRF) that may be at risk of deterioration as a result of lower water levels in Lake Michigan (Section 6)

The two primary drivers of climate change impacts are potential changes in temperature and in precipitation. As a result, the vulnerability analysis broadly identified environmental factors that may impact the District's facilities and operations as temperature and precipitation change. Environmental factors were grouped into five different types of responses, as shown in Figure ES-1.

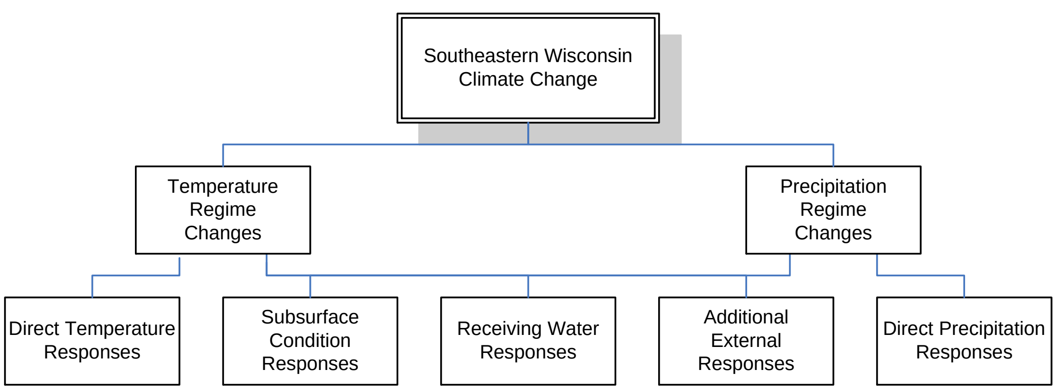

Figure ES-1. Projected Southeastern Wisconsin Climate Change Responses

These responses were traced to risks impacting District facilities and the risks were ranked using a qualitative system based on the likelihood and confidence that the response will happen and the severity of the impact on facilities. A list of “no regrets” action items was created to identify improvements that would be beneficial whether or not there is a change in the climate. Further monitoring is recommended before taking action on other risks that would only emerge if the climate change actually developed to a level of concern. Furthermore, ongoing situational awareness is recommended to identify if additional impacts have arisen or if the nature of the risk is better understood.

Impacts of climate change on the quantity and frequency of SSOs and CSOs, metershed flows, and WRF operations were evaluated for four scenarios, in addition to the baseline scenario. These scenarios are identified in Table ES-1. Two of the scenarios used a mid-century climate forecasting horizon and the other two scenarios used an end-of-century forecast horizon. For each forecast horizon, there are two scenarios to envelop the performance. The first climate change scenario (10%) has higher average annual temperatures but is otherwise similar to the baseline case in average precipitation amounts. The second climate change scenario (90%) is more severe, having a significantly greater average annual temperature. The mid-century 90% (CM-s90) and end-of-century 90% (CE-s90) datasets contain alternative climate change scenarios generated by statistically downscaling the global climate change modeling results to create data sets that represent local conditions. The 90% description means that these particular climate scenarios for mid-century and end-of-century cases are not the most extreme model cases, but they are scenarios that have more than average change characteristics. The 90% term is not a measure of any one specific parameter; it is a general term of severity.

Table ES-1. Climate Change Scenarios

Model Scenario	Climate Forecast Horizon	Climate Change Severity
Baseline	Existing climate conditions based on historic record (1940-2004)	
CM-s10	Mid-Century	Moderate Change; 10% Downscaled Network
CM-s90	Mid-Century	Larger Change; 90% Downscaled Network
CE-s10	End-of-Century	Moderate Change; 10% Downscaled Network
CE-s90	End-of-Century	Larger Change; 90% Downscaled Network

Precipitation changes under the climate change scenarios are reflected more as a change in distribution rather than an overall increase in the average annual amount. The climate change scenarios show a pattern of increasing precipitation intensity in a few larger events, but a decrease in the size and frequency of many of the smaller events. The month-to-month variation in precipitation, in which the amount has traditionally been concentrated in the summer, is less so in the climate change scenarios. Most of the quantity is still in the summer, but more is expected in the spring and fall, with a small decrease in the late summer.

Temperature changes may be more important than changes in precipitation. The average temperatures are projected to increase in the climate change scenarios, with the highest temperatures in the CE-s90 scenario. Some risk factors are directly tied to the temperature but others are a consequence of the higher rates of potential evapotranspiration (PET) that is predicted to accompany the temperature change. The average annual PET increased from 29.1 inches/year in the baseline scenario to 47.1 inches/year in the CE-s90 scenario. This increase in annual PET was significantly greater than the change in average annual precipitation, which was 0.9 inches/year greater in CE-s90 than in the baseline scenario. Not all of the impacts are adverse to the District's mission. For example, the simulated SSO frequency and volume decreased in the climate change scenarios.

The MACRO and Flow Forecasting System (FFS) models were used to evaluate the conveyance system. Simulations from the MACRO model were used to quantify the change in the frequency and volume of SSOs and CSOs. The results showed that from the baseline scenario to the CE-s90 scenario, the simulated CSO frequency increased 10% and the simulated annual CSO volume increased 27%. In addition, the overall trend indicates that there will be fewer SSO events and most of the SSOs will have smaller volumes, as indicated by the simulation results that showed SSO volume was 25% less in CE-s90 as compared to the baseline scenario. The reduction in the number of SSOs is most likely a consequence of the increased PET. As these results are based on calculated values for PET, monitoring actual evapotranspiration would improve the understanding of this environmental parameter which may be increasingly important in the future. The FFS model simulations were used to evaluate the change in metershed flows. A flow frequency analysis used long-term simulation results to estimate the peak flow values for recurrence intervals between 1- and 100-years. The 10-year peak flows were tabulated to compare the climate scenarios. For many metersheds, the 10-year peak flow values did not change significantly. For those that did change, the increase from the baseline scenario to the CM-s90 scenario was greater than the change to the CE-s90 scenario. The increase in mid-century values was generally no more than 10% greater than the baseline scenario and the increase in end-of-century values was generally no more than 6% greater than the baseline scenario.

The watercourse system was evaluated for changes in both high and low flow conditions. Peak flows are important for managing the floodplains and protecting against flooding but low flow periods are important for the viability of aquatic life and riparian ecosystems. Flows were evaluated for selected reaches in the Kinnickinnic and Menomonee rivers and changes due to climate were quantified by comparing the flows for different recurrence intervals. For the high flow conditions, the climate change scenarios had elevated peak flow values as compared to the baseline scenario. The 100-year flows were up to 16% greater in the CM-s90 scenario than for the baseline scenario; simulated 10-year peak flow values ranged from 6% to 13% greater than those for the baseline scenario. Simulated low flows were evaluated using three statistical metrics that are commonly used by the United States Environmental Protection Agency (EPA). All three metrics gave the same approximate decrease in low flow, which showed that although the percent decrease is significant (up to 73%), the absolute incremental decrease is small. Therefore, it is likely the lowest flows will not be impacted based on the scenarios analyzed.

The precipitation event frequency and depth were also evaluated and used to infer the impact of climate change on the performance of green infrastructure facilities. More precipitation was simulated in the climate change scenarios, but this quantity was carried in fewer precipitation events. From the baseline scenario to the CE-s90 scenario, the average annual precipitation increased 3%, but the average frequency of events decreased 9%. The climate change scenarios also showed a more uniform distribution of precipitation, meaning that the pattern of dry winters and wet summers that is characteristic of the baseline climate is likely to become less varied if the climate changes. Based on the simulation results, it appears that green infrastructure will be effective in dealing with most of the storms and most of the annual rain volume, but green infrastructure will not be utilized as fully or as frequently in the climate change scenarios as compared to the baseline scenario. The changes observed in the simulation results are typically less than 10%. Given the multitude of physical factors that influence the performance of green infrastructure, it is unlikely that the small changes simulated in this analysis that are associated with climate change would be observable in practice.

Also investigated was the risk of degradation of wood piles at the Jones Island WRF in response to lower water levels in Lake Michigan that may result from climate change. The conclusion of this investigation was that some of the wood piles at the West Plant Secondary Clarifiers, East Plant Secondary Clarifiers, West Plant Mixed Liquor Channels, and the breakwall and dock could be subject to deterioration due to drying if Lake Michigan water levels decrease.

In summary, the most significant findings from the District Climate Change Vulnerability Analysis are as follows:

1. Some larger precipitation events are expected to be more intense
2. Smaller precipitation events are expected to be smaller in size and less frequent
3. More precipitation is expected to fall as rain rather than snow in the winter months
4. Average temperature is expected to increase with more frequent heat waves
5. The increased temperature will likely result in greater evapotranspiration, which may offset some of the effects of increased precipitation intensity, particularly in the 2100 time-frame
6. No significant increase in peak wastewater flows is projected in the separate sewer area. A moderate increase in the average annual CSO volume may occur.
7. Higher peak runoff from more intense precipitation events may result in a decrease in the level of protection provided by flood management facilities
8. Higher temperatures and extended drought periods may lead to less infiltration to sewers, resulting in increased potential for odor and corrosion of wastewater facilities
9. Higher temperatures and extended drought periods may lead to decreased average and low flows in jurisdictional watercourses, resulting in a degradation of aquatic habitat and water quality, and a decrease in aquatic species viability
10. Potentially lower Lake Michigan levels could result in lower groundwater levels at the Jones Island WRF, resulting in dry rot of some wood piles

To address these risks, it is recommended that the District undertake the following:

1. Implement “no-regrets” actions that will be beneficial to the District whether or not climate change occurs
2. Monitor trends in local factors that are indicators of climate change
3. Monitor climate change research on changes in precipitation and temperature and update evaluations of impacts on District facilities if research indicates significant changes from assumptions used in this study
4. Consider the use of corrosion resistant materials and linings when replacing or rehabilitating sewers and pump stations and evaluate the need for odor control measures if an increasing trend in H2S is observed.
5. Investigate impacts of decreased watercourse low flows on aquatic habitat, water quality, and aquatic species viability
6. As green infrastructure is implemented, evaluate its effectiveness with regards to different rainfall distributions to assess how changes in distributions with climate change may impact the effectiveness of green infrastructure
7. Perform physical inspection of selected wood piles for Jones Island facilities that may have been exposed to drying during the low Lake Michigan water level/low groundwater period in 2012 to assess whether deterioration has occurred, which could be indicative of potential deterioration if climate change results in more frequent periods of low groundwater levels

Section 1:

Introduction

The Milwaukee Metropolitan Sewerage District (District) is undertaking a risk management approach to climate adaptation and consequently decided to undertake a vulnerability analysis to assess how soon the impacts may materialize at a level to present a meaningful threat to existing and planned facilities and operations. The objectives of the analysis were to:

- Provide information for the District to make decisions on capital improvements and operational strategies in the face of changing hydrologic and climate conditions
- Assess how soon climate change impacts may materialize at a level to present a meaningful threat to existing or planned facilities and operations
- Quantify risk that will aid in developing adaption strategies

This analysis is an extension of a previous District study that was conducted by Dr. Sandra McLellan of the Great Lakes Water Institute and Mike Hahn of the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in 2011 (McLellan, S., et. al., August 30, 2011). The McLellan study focused on how climate change might impact the conveyance system in 50 years. The District wanted to expand upon this study and look at the impacts of climate change on the conveyance system, watercourses, and water reclamation facilities (WRFs) within the District service area in 50 years (mid-century), but also in 100 years (end-of-century).

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Section 2:

Vulnerability Analysis

This climate change vulnerability analysis has been developed to use the current state of knowledge to assess how soon impacts of climate change may materialize at a strong enough level to present a meaningful threat to existing or planned District facilities and operations. Historically, rainfall and temperature have both been cyclical, and climate records indicate that southeastern Wisconsin has gotten somewhat warmer and wetter over the last 60 years (Wisconsin Initiative on Climate Change Impacts [WICCI] 2011). In southeastern Wisconsin, potential changes to the climate regime include, but are not limited to, temperature and precipitation that may produce changes in evaporation, more frequent and intense rainfall events, or changes in the frequency of droughts. These direct effects, as well as hydrologic responses including increased spring runoff, changes to lake and river levels, floodplain expansion, changes to vegetative communities and changes in wastewater conditions, could affect District facilities and/or the way they are operated. Of particular relevance is the strong likelihood that warmer winter and spring temperatures will lead to rain for precipitation events that currently result in snow.

For the purposes of this study, climate change “responses” have been defined as the specific changes to the natural system that result from projected changes in the climate regime. Examples of climate change responses are warmer soil temperatures and more frequent intense rainfall events. The effect of climate change responses on specific infrastructure elements are referred to as “impacts,” which include increased maintenance, changes to treatment processes and other additional investments of District time or resources. For engineering purposes, risk is defined as the product of probability and consequences, so the risk associated with an individual climate change “response” is defined as a product of both the likelihood of that response occurring and the magnitude of any resulting impacts in terms of the effort the District would have to undertake to address them. In this report, the magnitude of impact (in terms of District effort) given the occurrence of a climate change response is referred to as “vulnerability.” This report documents the steps taken in order to:

- Estimate the likelihood of specific climate change responses in southeastern Wisconsin
- Determine the impacts that these climate change responses, should they occur, would have on specific District facilities and service systems in terms of their vulnerability to reduced function given the projected magnitude of change
- Project the risk to District facilities and service systems, defined as a function of the likelihood of climate change responses and the vulnerability to the change
- Develop a list of adaptation actions to address situations where projected changes could have a significant effect on facilities and operations
- Recommend a list of next steps that serve as a prudent response to the risks of climate change determined in this study

2.1 Likely Climate Change Responses in Southeastern Wisconsin

In 2011, WICCI issued a report of the scientific consensus regarding ongoing and projected future climate change impacts in Wisconsin. In addition to the general analysis of statewide conditions, the

WICCI report includes a specific appendix developed by the "Milwaukee Working Group," which focuses specifically on the southeastern Wisconsin region.* The two primary drivers of climate change impacts in southeastern Wisconsin were determined to be potential changes in temperature regime and potential changes in precipitation regime. Notably, the region is not likely to be exposed to issues that drive climate change planning for infrastructure agencies in other areas, such as loss of water supply, increased wildfires, or sea level rise.

On October 24, 2013, a workshop was conducted with researchers, engineers, and other District staff to evaluate the conclusions of the WICCI report, determine what information had been developed since the completion of the WICCI report, generate input regarding a preliminary list of climate responses, and begin to identify potential impacts to District facilities. The workshop participants included:

- Tim Bate, PE (District)
- David Bennett, PE (Brown and Caldwell)
- Tom Chapman, PE (District)
- Bill Farmer, PE (District)
- Debra Jensen (District)
- Mike Hahn, PE (SEWRPC)
- David Lorenz, Ph.D. (UW-Madison)
- Christopher Magruder (District)**
- Sandra McClellan, Ph.D. (UW-Milwaukee)
- Rob Montgomery, PE (Montgomery Assoc.)
- David Perry, PE Ph.D. (Brown and Caldwell)
- Ken Potter, Ph.D. (UW-Madison)**
- Cari Roper, PE (District)
- Karen Sands, AICP (District)
- Stefan Schnitzer, Ph.D. (UW-Milwaukee)
- Rusty Schroedel, PE (Brown and Caldwell)
- Michael Schwar, PE Ph.D. (Montgomery Assoc.)

*- Summary of WICCI report and hyperlink to full document included in "References" section

**- Unable to attend, interviewed individually

Based on input from the workshop participants and further literature research arising from the workshop discussion, a list of 26 potential climate change responses was developed. For organizational purposes the list of expected responses was divided into five response groups (Figure 2-1):

- Direct temperature responses
- Direct precipitation responses
- Subsurface condition responses
- Receiving water responses
- Additional external responses

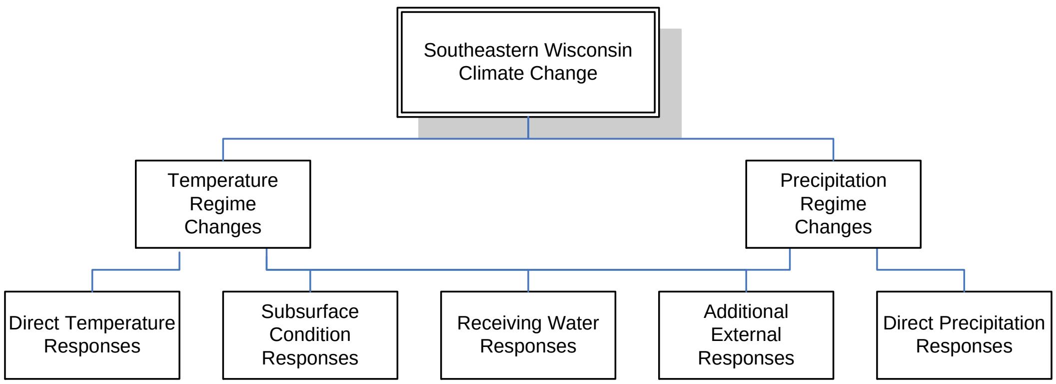

Figure 2-1. Projected Southeastern Wisconsin Climate Change Responses

The direct temperature responses (Figure 2-2) identified are:

- Increased air temperatures
- Increased incidence of heat waves (consecutive days of very high temperatures)
- Warmer soil temperatures

The direct precipitation response group (Figure 2-3) includes:

- Winter and early spring precipitation occurring as rain instead of snow
- Increased rainfall for frequent storm events
- Increased intensity and frequency of extreme rain and wind events
- Increased total annual precipitation
- Increased occurrence of summer drought
- Increased occurrence of freezing rain

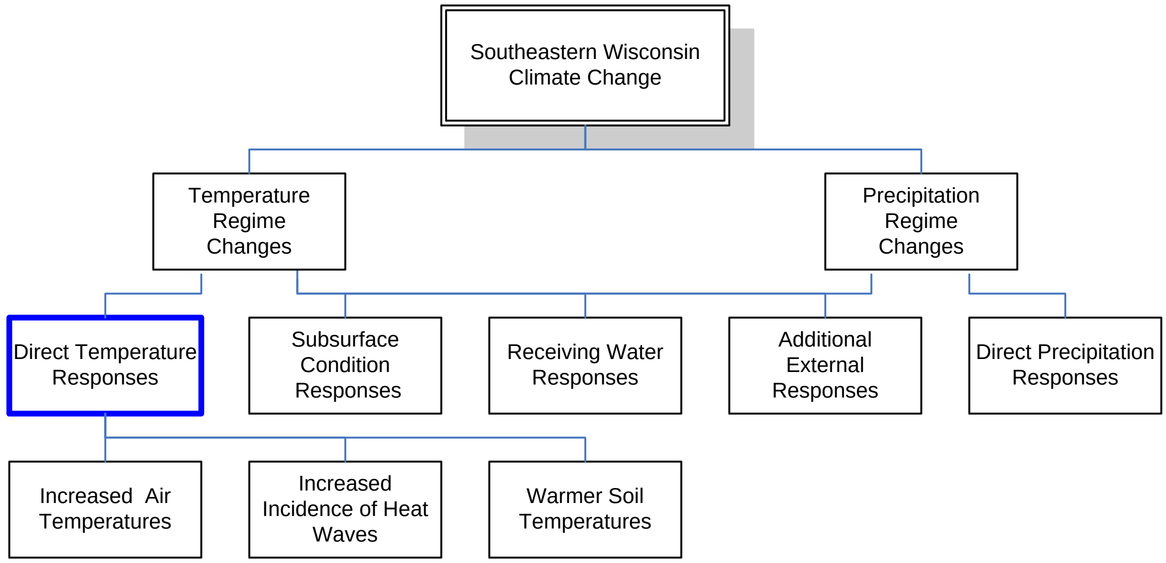

Figure 2-2. Southeastern Wisconsin Temperature Responses to Climate Change

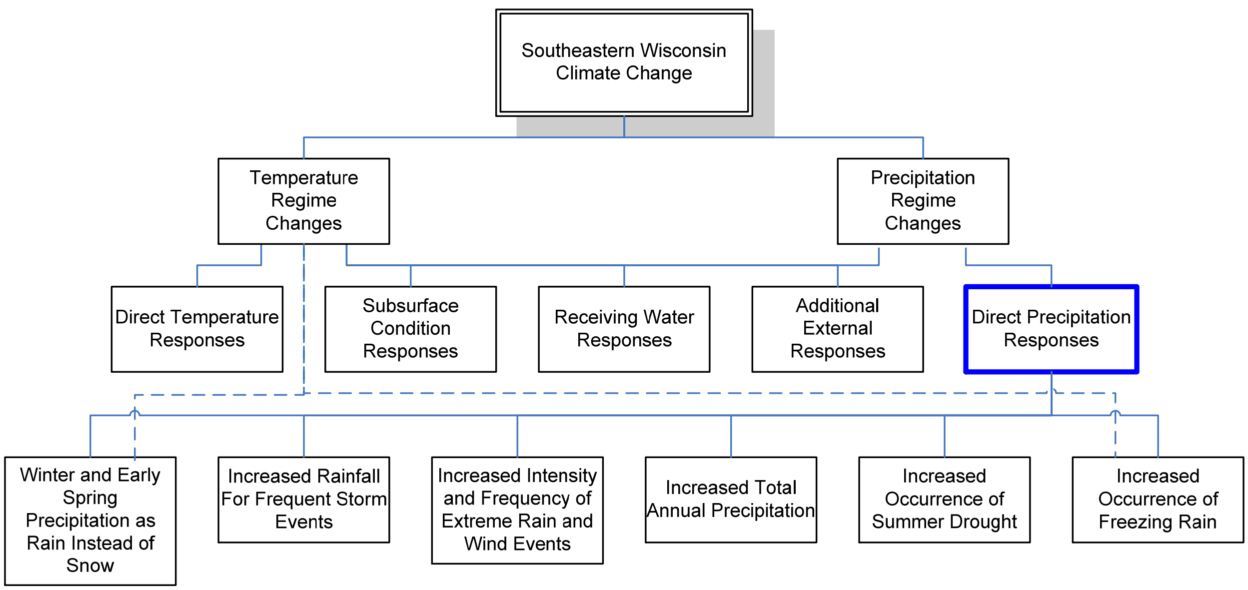

Figure 2-3. Southeastern Wisconsin Precipitation Responses to Climate Change

(Dashed line indicates temperature regime also a factor for certain responses)

Subsurface condition responses (Figure 2-4) include:

- Higher spring recharge, groundwater and soil moisture levels
- Lower late summer soil moisture levels
- Lower late summer groundwater levels
- More frequent freeze-thaw cycles

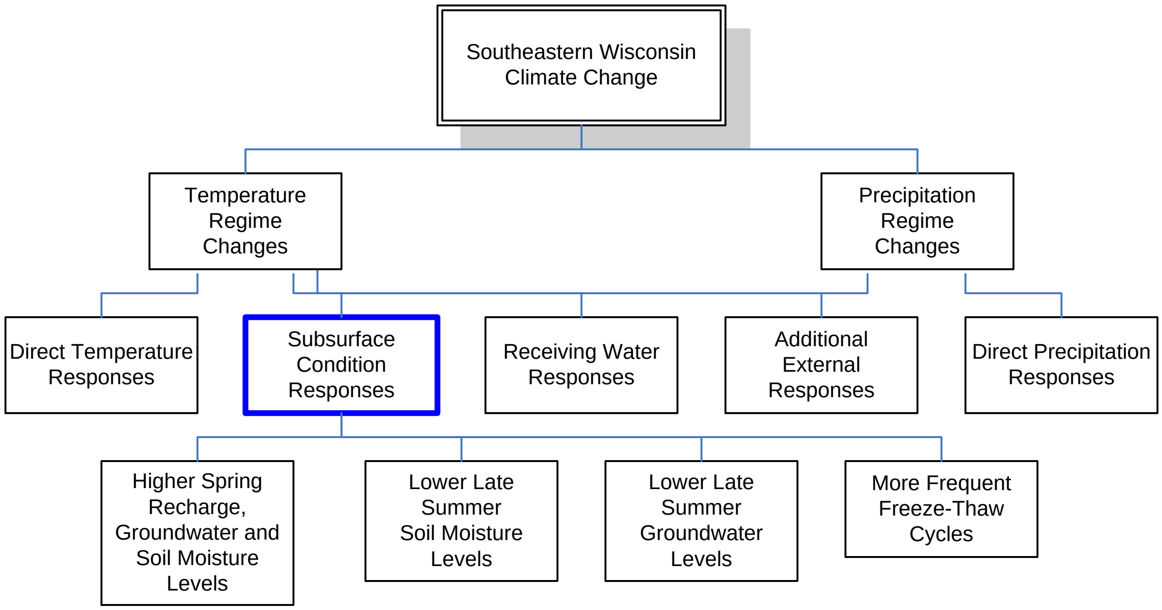

Figure 2-4. Southeastern Wisconsin Subsurface Condition Responses to Climate Change

Identified receiving water responses (Figure 2-5) are:

- Lake Michigan
  - Water level increases
  - Water level decreases
  - Warmer water temperatures
  - Increased watershed pollutant loads
- Watercourses
  - Increased flows during frequent events
  - Increased flows during extreme events
  - Lower watercourse base flows and levels
  - Warmer watercourse flows
  - Increased pollutant loadings from watersheds

Also, several additional external responses arising from climate change (Figure 2-6) were identified:

- Increases in external energy costs (costs for energy not produced by District)
- Reduced air quality
- Demographic shifts
- Implementation of water conservation measures

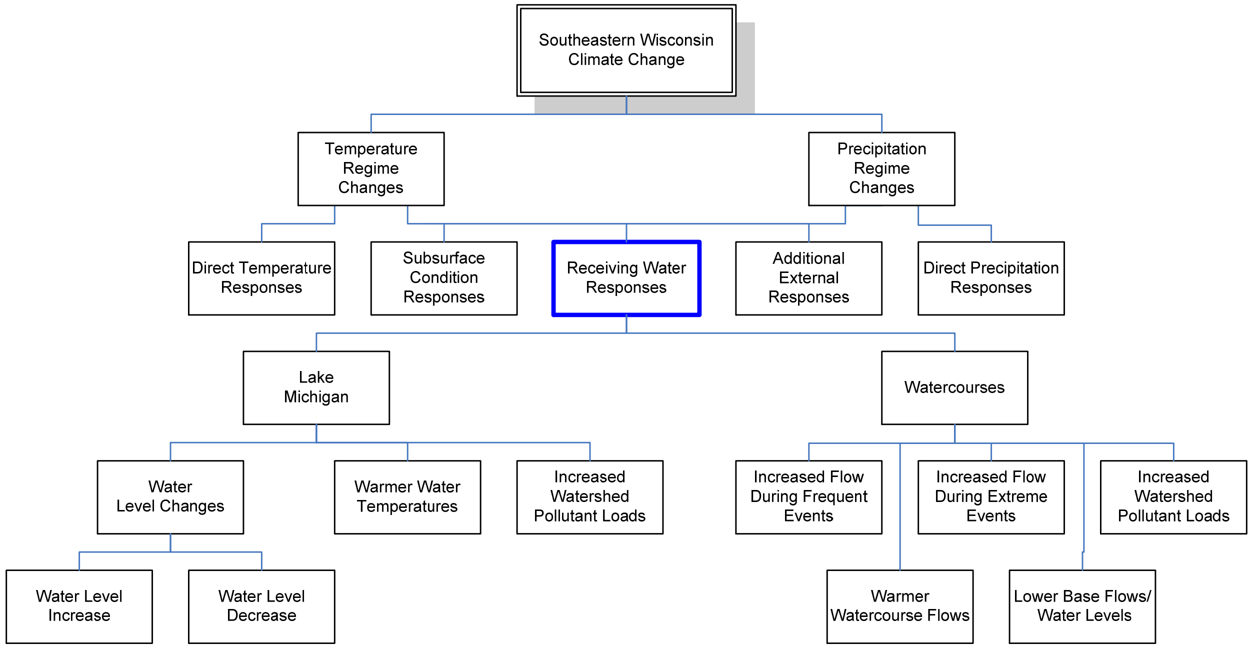

Figure 2-5. Southeastern Wisconsin Receiving Water Responses to Climate Change

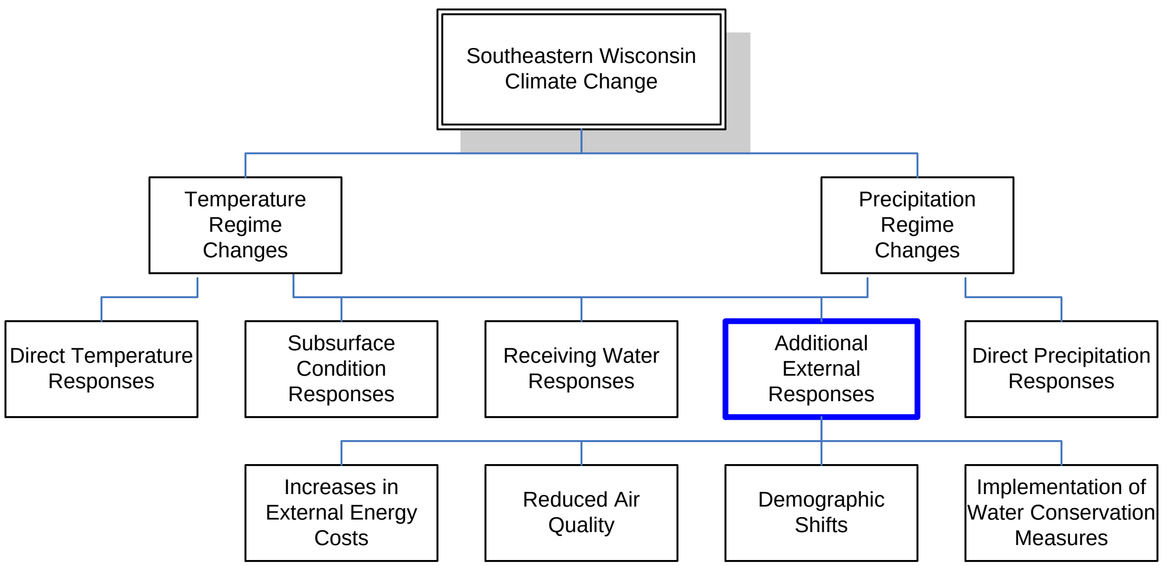

Figure 2-6. Southeastern Wisconsin Additional External Responses to Climate Change

2.2 Likelihood and Confidence in Projected Climate Change Responses

Based on input from the workshop and a review of available literature, a projection of the magnitude of climate change responses (Significant, Moderate, Small or No Change) was developed for the periods 2014-2050 and 2014-2100. Appendix A provides an annotated bibliography of the literature that was included in this review.

A judgment was also made as to the significance of this projected change relative to existing conditions, and the confidence (from a weight-of-evidence perspective) that this change will occur. On the basis of the judged significance and the confidence levels, the "likelihood of change response" was determined to be either high, moderate, or low using Table 2-1.

Table 2-1. Likelihood Determination Matrix

		Magnitude of Projected Change		
Confidence Level		None/ Small	Moderate	Significant
	High	Low	High	High
	Moderate	Low	Moderate	High
	Low	Low	Moderate	Moderate

2.2.1 Projected Responses by 2050

Summaries of the bases of the projected 2014-2050 climate change responses used for this analysis are provided in the following tables. Table 2-2 presents the projected temperature responses, Table 2-3 presents the projected precipitation responses and Table 2-4 presents the responses related to subsurface conditions. The projected receiving water responses are presented in Table 2-5 and the additional external responses are in Table 2-6. The "Sources" columns in these tables refer to either the references listed at the end of this document or communications with Dr. David Lorenz and Dr. Ken Potter, both climate change response researchers at the University of Wisconsin – Madison.

Table 2-2. Projected Temperature Responses by 2050

Physical Responses to Climate Change	Changes by 2050: Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increased Air Temperatures	Summer average temperature increases by 5 degrees.	Considered to represent significant relative change from existing. About four times greater rate than experienced since 1950.	High	High	WICCI
Increased Incidence of Heat Waves	Number of days with high temperatures exceeding 90 degrees in SE Wisconsin increases from 12 to 25 per year.	Considered to represent significant relative change from existing. Approximate doubling of frequency of very hot days.	High	High	WICCI
Warmer Soil Temperatures	Increase by 5 degrees (based on annual air temperature).	Considered to represent significant relative change from existing. About four times greater increase than experienced since 1950.	High	High	WICCI

Table 2-3. Projected Precipitation Responses by 2050

Physical Responses to Climate Change	Changes by 2050				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Winter and Early Spring Precipitation as Rain Instead of Snow	Rainfall in March increase from 1.0 to 1.8 inches.	Considered to represent significant change from existing. About 50% increase in precipitation as rain rather than snow in March.	High	High	WICCI
Increased Rainfall During Frequent (such as 2-yr) Storm Events	10 to 20% increase in precipitation quantiles (the amount of rainfall corresponding to a given probability) relative to existing.	Considered to represent significant relative change from existing. Greater than 75% likelihood of increased number of days with 2.0 inches rain.	High	High	K. Potter D. Lorenz
Increased Intensity and Frequency of Extreme Rain and Wind Events	10 to 20% increase in 10-yr to 100-yr rainfall depths.	Considered to represent moderate relative change from existing. Continuation of recent trend of increasing frequency of intense events.	Moderate	Moderate	Vavrus & Behnke
Increased Total Annual Precipitation	Slight increase in annual precipitation (no scientific consensus on the magnitude of annual increase at this time).	Considered to represent moderate relative change from existing. Continuation of recent trend of increasing wetness.	Moderate	Moderate	WICCI, Cruce & Yurkovich
Increased Occurrence of Summer Drought	Unquantified increase in occurrence of extended periods of below-normal rainfall.	Assume moderate relative change from existing. Model results are not conclusive.	Moderate	Moderate	WICCI
Increased Occurrence of Freezing Rain	Unquantified increase in number of days per year rain falls on frozen ground or freezes on contact.	Assume moderate relative change from existing.	High	High	WICCI

Table 2-4. Projected Subsurface Condition Responses by 2050

Physical Responses to Climate Change	Changes by 2050				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Higher Spring Recharge, Groundwater and Soil Moisture Levels	Anticipate significant increases in recharge in non-urban areas.	Assume moderate relative change from existing. Although recharge will increase in some areas, effects in urban areas likely to be less.	High	High	K. Potter
Lower Late Summer Soil Moisture Levels	More frequent and longer durations of desiccated soil conditions.	Assume moderate relative change from existing.	High	High	WICCI, Cherkauer & Sinha
Lower Late Summer Groundwater	Increased overall recharge may or may not offset increased phreatic evapotranspiration - evidence is conflicting.	Assume moderate relative change from existing.	Low	Moderate	Cherkauer & Sinha
More Frequent Freeze-thaw Cycles	Shorter duration of frozen ground.	Assume significant relative change from existing.	High	High	WICCI

Table 2-5. Projected Receiving Water Responses by 2050

Physical Responses to Climate Change	Changes by 2050 Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increased Lake Michigan Water Level	Lake levels are likely to continue to fluctuate. While lower levels are likely, the possibility of higher levels at times cannot be dismissed.	Assume no relative change from existing. Likely to remain within relatively narrow historical range.	Low	Low	IJC **
Decreased Lake Michigan Water Level	Lake levels are likely to continue to fluctuate. While lower levels are likely, the possibility of higher levels at times cannot be dismissed.	Assume moderate relative change from existing. Likely to remain within relatively narrow historical range.	Moderate	Moderate	IJC
Warmer Lake Michigan Water Temperatures	Warming of lake temperature at a greater rate than air temperature due to compounding effects of reduced ice cover. Increase 3.4 to 3.9 ^{o}F by 2050.	Considered to represent significant relative change from existing. Increase of 0.05-0.08 ^{o}C/yr in Lake Michigan from 1979-2006.	High	High	Austin and Colman, Cruce & Yurkovich
Increased Pollutant Loads to Lake Michigan*	Slight increase in loads from contaminated aquifers and possibly from watersheds.	Assume moderate relative change from existing. Existing models do not show a clear trend regarding the effects of climate changes on pollutant loading in the region.	Moderate	Moderate	McLellan, Bravo & Hahn
Increased Watercourse Flow During Frequent (such as 2-year) Events	Increased intense rainfall leads to proportionally increased peak flows.	Considered to represent significant relative change from existing. Continuation of recent trend of increasing frequency of intense events.	High	High	Cherkauer & Sinha
Increased Watercourse Flow During Extreme (such as 100-year) Events	Increased intense rainfall leads to proportionally increased peak flows.	Considered to represent moderate relative change from existing. Continuation of recent trend of increasing frequency of intense events.	Moderate	Moderate	Vavrus & Behnke
Lower Watercourse Base Flows/Levels	Increased overall recharge may or may not offset increased phreatic evapotranspiration - evidence is conflicting.	Assume moderate relative change from existing.	Low	Moderate	Cherkauer & Sinha
Warmer Watercourse Flows	Baseflow temperatures increase somewhat less rapidly than air temperature (offset a bit by recharge inflows).	Assume moderate relative change from existing.	High	High	WICCI
Increased Pollutant Loadings from Watersheds*	Slight increase in loads from contaminated aquifers and possibly from watersheds.	Assume moderate relative change from existing. Existing models do not show a clear trend regarding the effects of climate changes on pollutant loading in the region.	Moderate	Moderate	McLellan, Bravo & Hahn

**- Including contaminants from shallow aquifer, phosphorus from increased volumes of noncontact cooling water and other watershed pollutant sources*

***- International Joint Commission*

Table 2-6. Projected Additional External Responses by 2050

Physical Responses to Climate Change	Changes by 2050				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increases in External Energy Costs	Increased energy sources will be required to meet demand, likely increasing energy costs.	Assume moderate relative change from existing.	Moderate	Moderate	U.S. Dept. Energy
Reduced Air Quality	Increased incidence of ground level ozone.	Assume moderate relative change from existing.	Moderate	Moderate	USGCRP *
Demographic Shifts	Reduced water availability in other areas may promote population shifts to SE Wisconsin because of adequate water supply.	Assume no relative change from existing.	Moderate	Low	EPA 2009
Implementation of Water Conservation Measures	Reduced water availability may promote the implementation of conservation measures.	Assume small relative change from existing.	Moderate	Low	Projection of MMSD usage data

**- United States Global Change Research Program*

2.2.2 Projected Responses by 2100

As in the previous section, the climate change responses used in this analysis for the period 2014-2100 are presented in tables that follow. The projected temperature, precipitation and subsurface condition responses are shown in Table 2-7, Table 2-8 and Table 2-9, respectively. The receiving water responses and additional external responses are shown in Table 2-10 and Table 2-11 respectively. Where scientific information is not sufficient to project responses through 2100, continuation of projected trends is assumed.

Table 2-7. Projected Temperature Responses by 2100

Physical Responses to Climate Change	Changes by 2100				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increased Air Temperatures	Continued or accelerated increasing trend.	Assume significant relative change from existing. Change largely dependent on carbon use trends over the next decades.	High	High	D. Lorenz, K. Potter
Increased Incidence of Heat Waves	Number of days with high temperature > 90 degrees in Chicago increases to between 36 and 72, change of a similar magnitude assumed for SE Wisconsin.	Considered to represent significant relative change from existing. Increase of 140 to 380% relative to 1961-1990 (15 per year).	High	High	Vavrus & Van Dorn
Warmer Soil Temperatures	Continued or accelerated increasing trend.	Assume significant relative change from existing. Change largely dependent on carbon use trends over the next decades.	High	High	*

**- Scientific information not sufficient to project responses through 2100; continuation of projected trends is assumed.*

Table 2-8. Projected Precipitation Responses by 2100

Physical Responses to Climate Change	Changes by 2100				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Winter and Early Spring Precipitation as Rain Instead of Snow	Continued increasing trend.	Considered to represent significant change from existing. Relatively large increases in winter and spring precipitation.	High	High	Cruce & Yurkovich
Increased Rainfall During Frequent (such as 2-yr) Storm Events	Between 1.9 and 2.5 days with rainfall > 4 cm each year.	Considered to represent significant relative change from existing. Amounts to 27 to 64% increase relative to 1961-1990 (1.5 per year).	High	High	Vavrus & Van Dorn
Increased Intensity and Frequency of Extreme Rain and Wind Events	Continued increasing trend.	Assume moderate relative change from existing. Existing models not sufficient to develop long-term predictions, but increases in extremes likely to become more statistically apparent.	High	High	*
Increased Total Annual Precipitation	Increased likelihood of increase.	Assume moderate change from existing. Models uncertain.	Moderate	Moderate	D. Lorenz
Increased Occurrence of Summer Drought	Continued increase.	Assume significant relative change from existing.	Moderate	High	Cruce & Yurkovich
Increased Occurrence of Freezing Rain	Unquantified increase in occurrence of freezing rain.	Assume moderate relative change from existing. Very limited information available.	High	High	*

**- Scientific information not sufficient to project responses through 2100; continuation of projected trends is assumed.*

Table 2-9. Projected Subsurface Condition Responses by 2100

Physical Responses to Climate Change	Changes by 2100				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Higher Spring Recharge, Groundwater and Soil Moisture Levels	Continued higher recharge in non-urban areas.	Assume moderate relative change from existing. Modeling inconclusive regarding long-term trends on precipitation-recharge-evapotranspiration balance.	High	High	*
Lower Late Summer Soil Moisture Levels	Continued trend of increasing desiccation.	Assume significant relative change from existing. Change consistent with air and soil temperature changes.	High	High	*
Lower Late Summer Groundwater	Increased overall recharge may or may not offset increased phreatic evapotranspiration - evidence is conflicting.	Assume moderate relative change from existing.	Low	Moderate	Cherkauer & Sinha
More Frequent Freeze-thaw Cycles	Continued trend of shorter frozen ground duration.	Assume significant relative change from existing.	High	High	*

**- Scientific information not sufficient to project responses through 2100; continuation of projected trends is assumed.*

Table 2-10. Projected Receiving Water Responses by 2100

Physical Responses to Climate Change	Changes by 2100				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increased Lake Michigan Water Level	More extreme water levels may occur, but at present the models are too limited to determine.	Assume no relative change from existing.	Low	Low	IJC
Decreased Lake Michigan Water Level	More extreme water levels may occur, but at present the models are too limited to determine.	Considered to represent moderate relative change from existing. For high emissions scenario, 2080 Lake Michigan water level on average 1.3 feet lower than 1970-1999 average.	Moderate	Moderate	IJC, Cruce & Yurkovich
Warmer Lake Michigan Water Temperatures	Average Lake Michigan water temperature expected to increase to 72-74.5 °F by 2071-2100.	Considered to represent significant relative change from existing. Increase 4.6-7.0 °F relative to 1970-2000.	High	High	Cruce & Yurkovich
Increased Pollutant Loads to Lake Michigan*	Slight increase in loads from contaminated aquifers and possibly from watersheds.	Assume moderate relative change from existing. Existing models do not show a clear trend regarding the effects of climate changes on pollutant loading in the region.	Moderate	Moderate	M. Hahn
Increased Watercourse Flow During Frequent (such as 2-year) Events	Number of days with flow exceeding the 30 year upper quintile value increase by 22-31%.	Considered to represent significant change from existing. Change from about 72 days per year to 88-94 per year.	High	High	Cherkauer & Sinha
Increased Watercourse Flow During Extreme (such as 100-year) Events	Assume continued increasing trend.	Assume moderate relative change from existing. Existing models not sufficient to develop long-term predictions.	Moderate	Moderate	**
Lower Watercourse Base Flows/Levels	Increased overall recharge may or may not offset increased phreatic evapotranspiration - evidence is conflicting.	Assume moderate relative change from existing.	Low	Moderate	Cherkauer & Sinha
Warmer Watercourse Flows	Continue on similar trajectory to air temperatures.	Assume significant relative change from existing.	High	High	**
Increased Pollutant Loadings from Watersheds*	Slight increase in loads from contaminated aquifers and possibly from watersheds.	Assume moderate relative change from existing. Existing models do not show a clear trend regarding the effects of climate changes on pollutant loading in the region.	Moderate	Moderate	M. Hahn

**- Including contaminants from shallow aquifer, phosphorus from increased volumes of noncontact cooling water and other watershed pollutant sources.*

***- Scientific information not sufficient to project responses through 2100; continuation of projected trends is assumed.*

Table 2-11. Projected Additional External Responses by 2100

Physical Responses to Climate Change	Changes by 2100				
	Specific Change Projected	Change Relative to Recent Changes	Confidence that Projected Change Will Occur	Likelihood of Change Relative to Existing	Sources
Increases in External Energy Costs	Increased energy sources will be required to meet demand, likely increasing energy costs.	Assume moderate relative change from existing.	Moderate	Moderate	U.S. Dept. Energy
Reduced Air Quality	Increased incidence of ground level ozone.	Assume moderate relative change from existing.	Moderate	Moderate	USGCRP
Demographic Shifts	Reduced water availability in other areas may promote population shifts to SE Wisconsin because of adequate water supply and more temperate climate.	Assume no relative change from existing.	Moderate	Low	EPA 2009
Implementation of Water Conservation Measures	Reduced water availability may promote the implementation of conservation measures.	Assume small relative change from existing.	Moderate	Low	*

**- Scientific information not sufficient to project responses through 2100; continuation of projected trends is assumed.*

2.3 Climate Change Impacts to District Facilities

The following “impact trees” (Figure 2-7 through Figure 2-11) characterize the likely direct negative impacts to District services and facilities that may arise from the climate change responses identified in the previous section. The list of impacts was developed by project members in consultation with District staff and intends to represent the range of known adverse effects that are likely to arise. Within the trees, the potential impacts to the District are listed in the shaded boxes, and they are organized under the climate change responses (in unshaded boxes) that produce the potential impact. In some cases, a cross-hatched box is added to clarify the mechanism by which the climate change response acts to produce the impact.

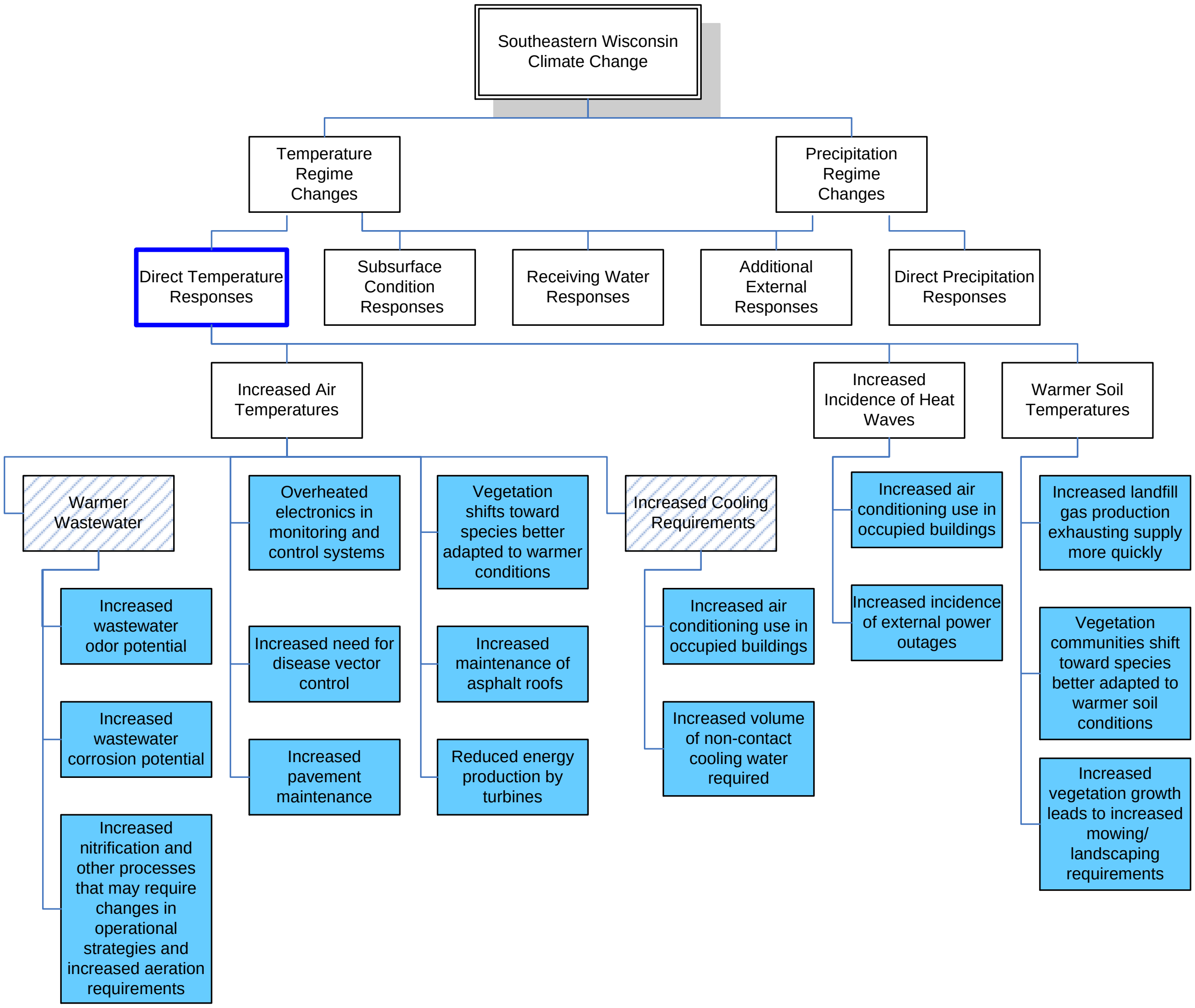

Figure 2-7. Potential Impacts on District Facilities Due to Temperature Responses to Climate Change

(hatched box indicates mechanism by which temperature response initiates facility impacts)

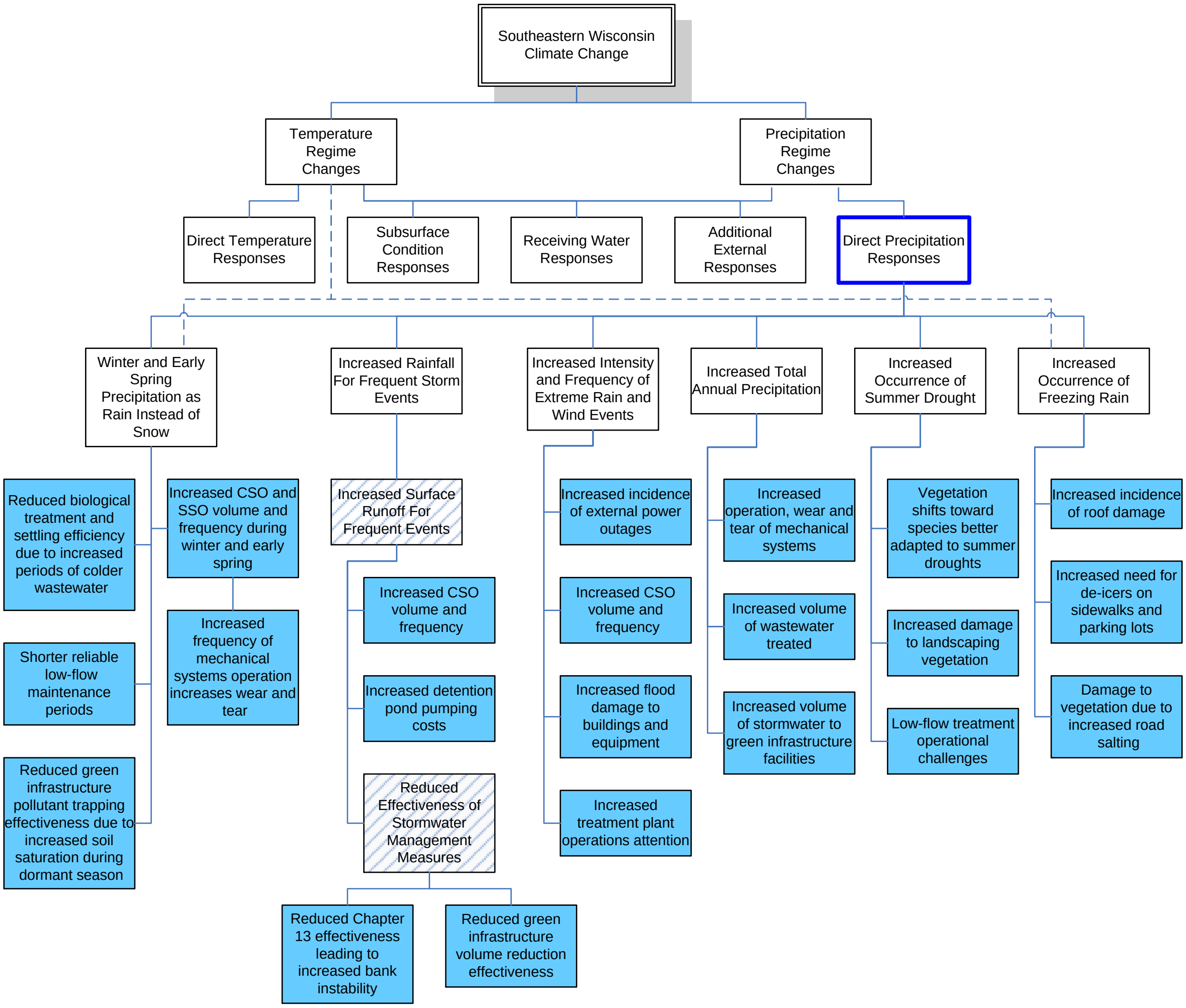

Figure 2-8. Potential Impacts on District Facilities Due to Precipitation Responses to Climate Change

(hatched box indicates mechanism by which precipitation response initiates facility impacts)

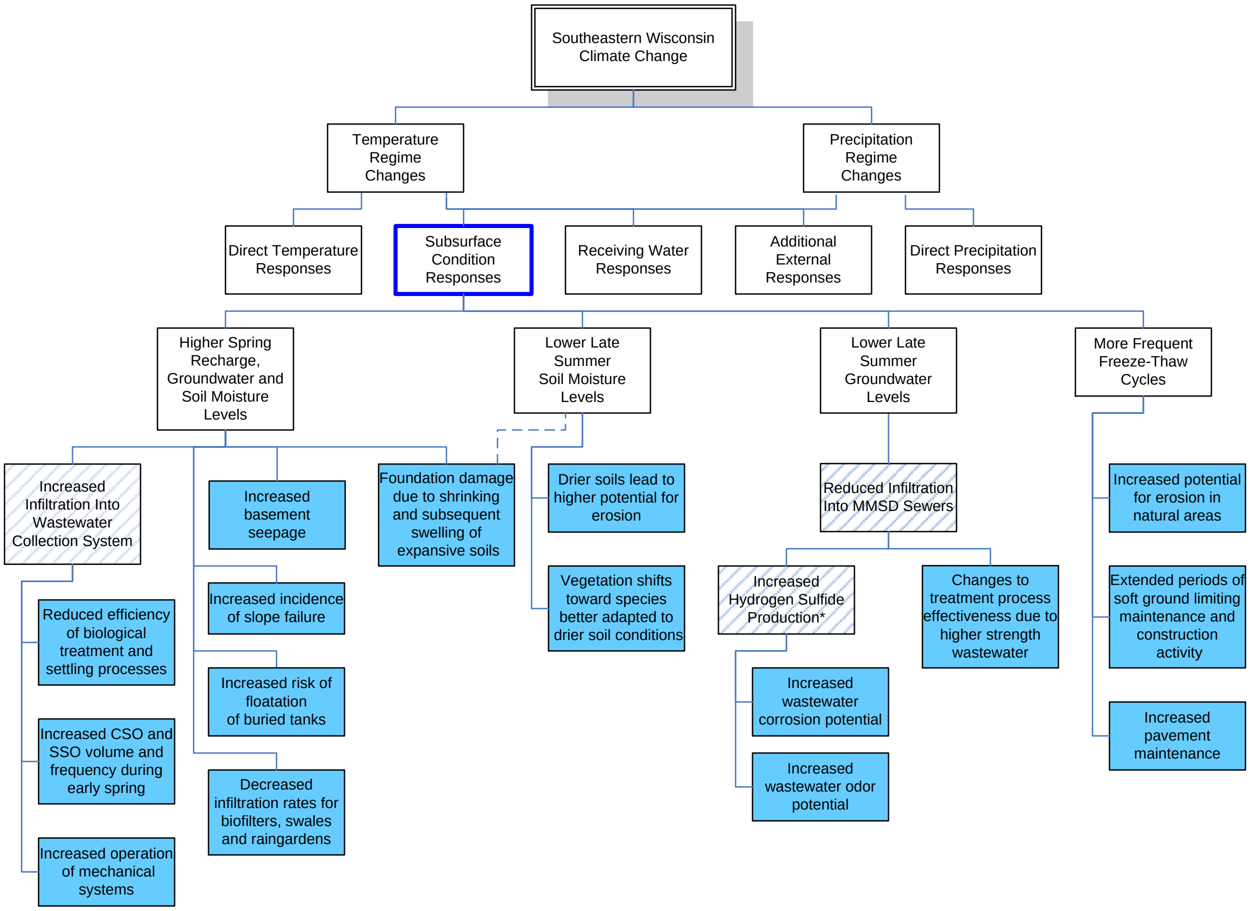

Figure 2-9. Potential Impacts on District Facilities Due to Subsurface Condition Responses to Climate Change

(hatched box indicates mechanism by which subsurface condition response initiates facility impacts, dashed line indicates partial contribution to impact from second response)

** - Based on observations during past drought events, wastewater quality is presumed to be more sensitive to reduced infiltration than to increases in temperature.*

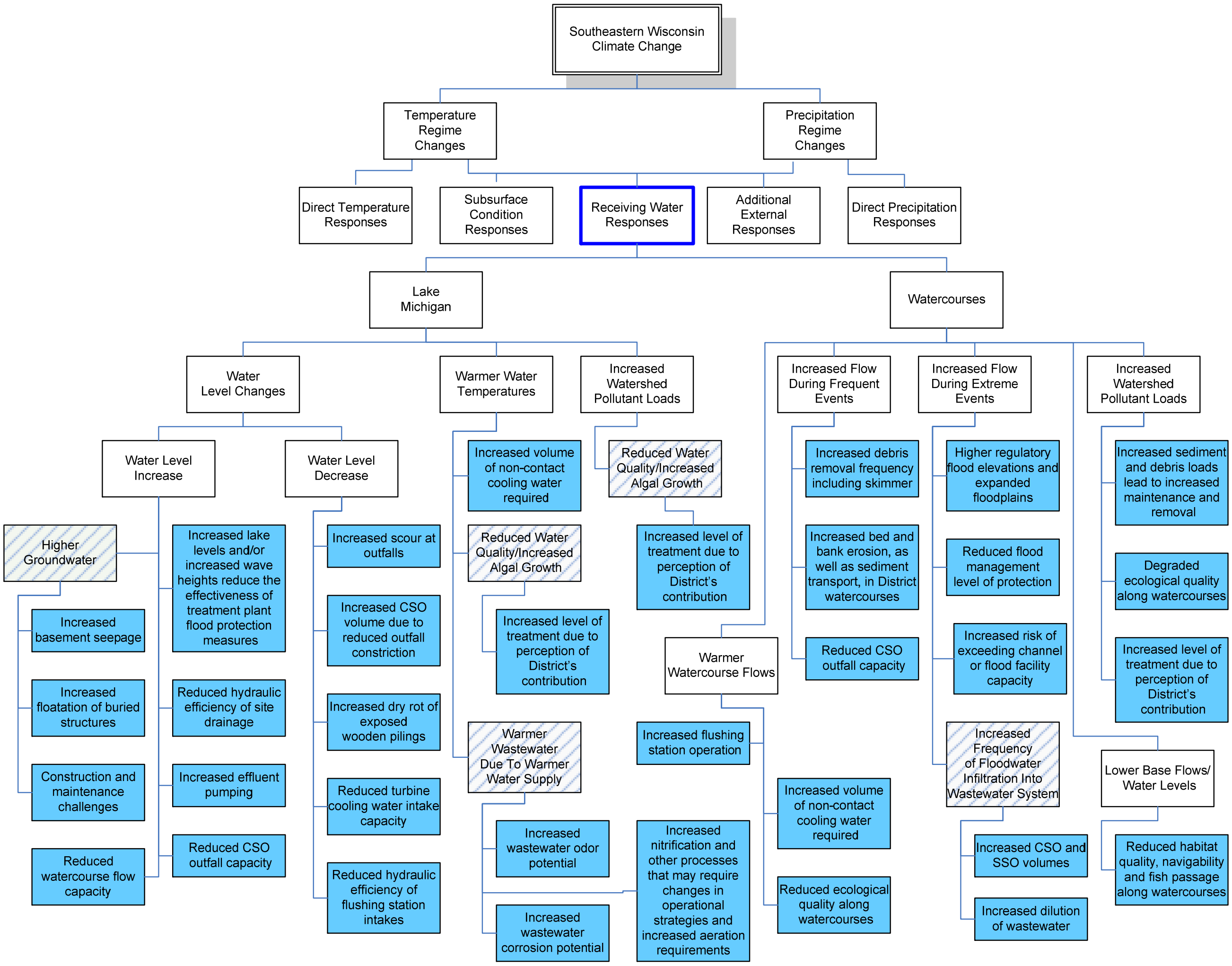

Figure 2-10. Potential Impacts on District Facilities Due to Receiving Water Responses to Climate Change

(hatched box indicates mechanism by which receiving water response initiates facility impacts)

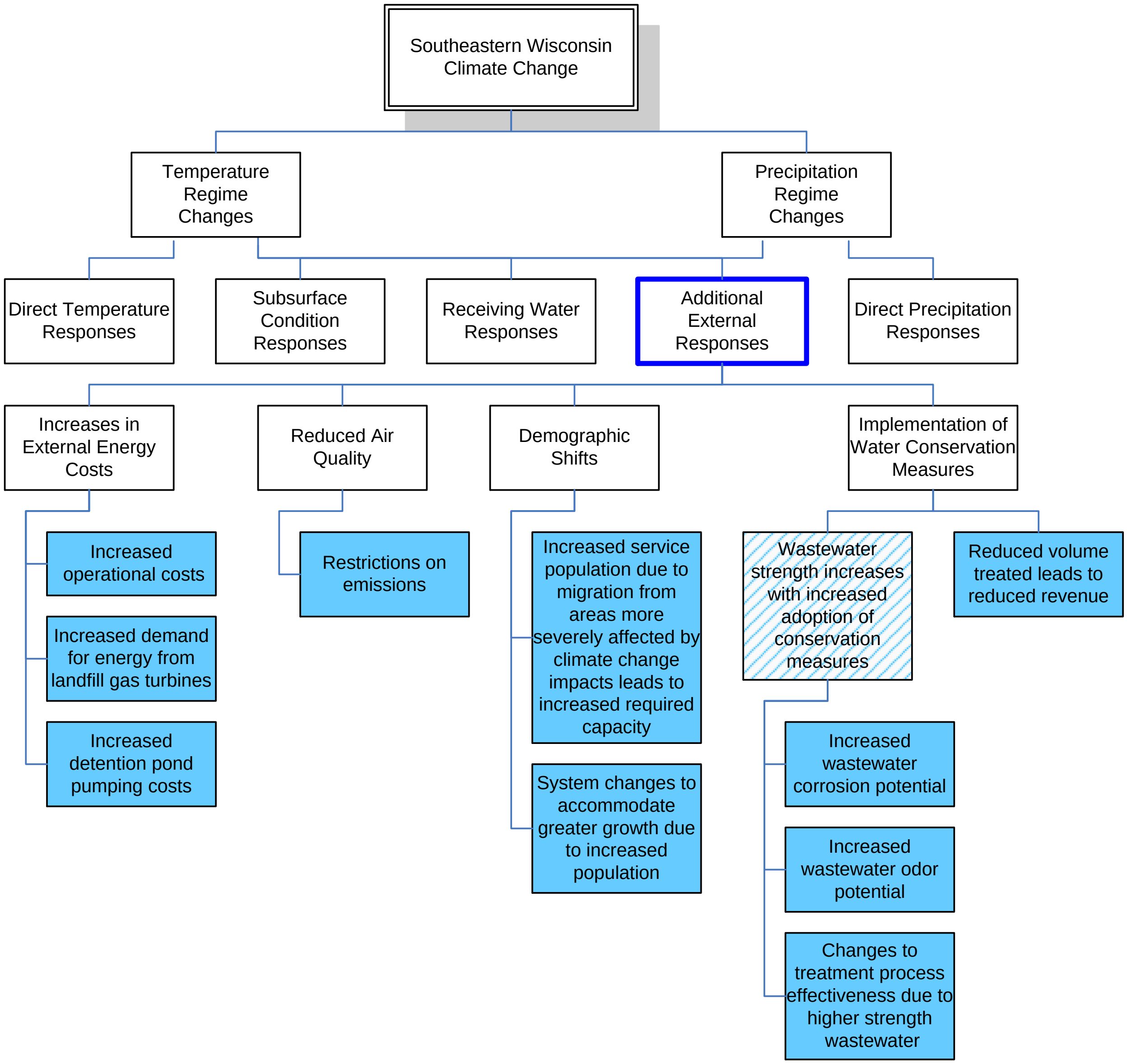

Figure 2-11. Potential Impacts on District Facilities Due to Additional External Responses to Climate Change

(hatched box indicates mechanism by which external response initiates facility impacts)

2.4 District Facilities Climate Change Vulnerabilities

Service areas and facilities likely to be affected by each specific potential impact were determined by project team specialists and District personnel using professional judgment and knowledge of District systems (Table 2-12 through Table 2-17) The vulnerability of each service area or facility to the projected magnitude of climate change response (high, medium or low, Table 2-2 through Table 2-11) was also assigned based on engineering judgment.

Table 2-12. District Service Impact and MIS Physical Impact Vulnerability to Potential Temperature, Precipitation and Subsurface Condition Climate Change Responses

		Service Impacts				Physical Impacts			
						MIS			
	Physical/External Responses to Climate Change	MIS/ISS	WRFs	Watercourses	Landfill Gas System	Pipes (1)	Manholes	Control Structures (2)	Pump Stations
Temperature Responses	Increased Air Temperatures		Increased nitrification and other processes due to warmer wastewater, possibly requiring changes in operational strategies and increased aeration requirements		Reduced energy production by turbines, increased volume of non-contact cooling water required for turbines	Increased corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater
Temperature Responses	Increased Incidence of Heat Waves		Increased incidence of external power outages					Increased incidence of external power outages, overheated electronics in monitoring and control systems	Increased incidence of external power outages
Temperature Responses	Warmer Soil Temperatures				Increased landfill gas production exhausting supply more quickly				
Precipitation Responses	Winter and Early Spring Precipitation as Rain Instead of Snow	Increased CSO and SSO volume and frequency during winter and early spring	Reduced biological treatment and settling efficiency due to increased periods of colder wastewater					Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods
Precipitation Responses	Increased Rainfall During Frequent (such as 2-yr) Storm Events	Increased CSO volume and frequency							
Precipitation Responses	Increased Intensity and Frequency of Extreme Rain and Wind Events	Increased CSO volume and frequency	Increased treatment plant operations attention, increased incidence of external power outages	(Addressed Under Receiving Water Responses)				Increased incidence of external power outages	Increased incidence of external power outages
Precipitation Responses	Increased Total Annual Precipitation		Increased volume of wastewater treated						Increased operation, wear and tear
Precipitation Responses	Increased Occurrence of Summer Drought		Low-flow treatment operational challenges						
Precipitation Responses	Increased Occurrence of Freezing Rain								
Subsurface Condition Responses	Higher Spring Recharge, Groundwater and Soil Moisture Levels	Increased CSO and SSO volume and frequency during early spring	Reduced biological treatment and settling efficiency						Increased operation, wear and tear
Subsurface Condition Responses	Lower Late Summer Soil Moisture Levels								
Subsurface Condition Responses	Lower Late Summer Groundwater		Changes to treatment process effectiveness due to higher strength wastewater			Increased wastewater corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration
Subsurface Condition Responses	More Frequent Freeze-thaw Cycles					Extended periods of soft ground limiting maintenance and construction activity	Extended periods of soft ground limiting maintenance and construction activity	Extended periods of soft ground limiting maintenance and construction activity	Extended periods of soft ground limiting maintenance and construction activity

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility	
High	(red)
Moderate	(yellow)
Low	(green)

Legend

DC - Diversion Chamber
DS - Diversion Structure
HQ - Headquarters
IS - Intercepting Structure
ISS - Inline Storage System
MIS - Metropolitan Interceptor Sewer
NSC - Near Surface Collector
WRF - Water Reclamation Facility

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Table 2-13. District ISS and WRF Physical Impact Vulnerability to Potential Temperature, Precipitation and Subsurface Condition Climate Change Responses

		Physical Impacts								
		ISS					WRFs			
	Physical/External Responses to Climate Change	Tunnel	Drop Shaft Systems	Access Shafts	Control Structures (3)	Inline Pump Station (4)	Unit Processes	Buildings	Pipelines (5)	Floodwalls
Temperature Responses	Increased Air Temperatures	Increased corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater	Increased odor and corrosion potential due to warmer wastewater		Increased odor and corrosion potential due to warmer wastewater	Increased air conditioning use, increased maintenance of asphalt roofs		
	Increased Incidence of Heat Waves				Increased incidence of external power outages, overheated electronics in monitoring and control systems	Increased incidence of external power outages	Overheated electronics in monitoring and control systems	Increased air conditioning use, increased pavement maintenance		
	Warmer Soil Temperatures									
Precipitation Responses	Winter and Early Spring Precipitation as Rain Instead of Snow	Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods, increased operation, wear and tear	Shorter reliable low-flow maintenance or construction periods		Shorter reliable low-flow maintenance or construction periods	
	Increased Rainfall During Frequent (such as 2-yr) Storm Events									
	Increased Intensity and Frequency of Extreme Rain and Wind Events				Increased incidence of external power outages	Increased incidence of external power outages		Increased flood damage to buildings and equipment		
	Increased Total Annual Precipitation					Increased operation, wear and tear				
	Increased Occurrence of Summer Drought									
	Increased Occurrence of Freezing Rain							Increased incidence of roof damage, increased need for deicers on sidewalks and parking lots		
Subsurface Condition Responses	Higher Spring Recharge, Groundwater and Soil Moisture Levels					Increased operation, wear and tear	Increased risk of floatation of buried tanks	Increased basement seepage		
	Lower Late Summer Soil Moisture Levels									
	Lower Late Summer Groundwater	Increased wastewater corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration	Increased wastewater odor and corrosion potential due to reduced infiltration		Increased wastewater odor and corrosion potential due to reduced infiltration			
	More Frequent Freeze-thaw Cycles						Extended periods of soft ground limiting maintenance and construction activity	Increased pavement maintenance		

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility	
High	(red)
Moderate	(yellow)
Low	(green)

Legend

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MIS - Metropolitan Interceptor Sewer
NSC - Near Surface Collector
WRF - Water Reclamation Facility

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Table 2-14. District Watercourse, Landfill Gas System, Green Infrastructure and Other Buildings Physical Impact Vulnerability to Potential Temperature, Precipitation and Subsurface Condition Climate Change Responses

		Physical Impacts					
		Watercourses		Landfill Gas System			
	Physical/External Responses to Climate Change	Channels	Flood Management Facilities	Pipeline	Structures	Green Infrastructure	Other Buildings and Fleet (6)
Temperature Responses	Increased Air Temperatures	Vegetation shifts toward species better adapted to warmer conditions, increased need for disease vector control	Vegetation shifts toward species better adapted to warmer conditions, increased need for disease vector control			Vegetation shifts toward species better adapted to warmer conditions	Increased air conditioning use, increased maintenance of asphalt roofs
Temperature Responses	Increased Incidence of Heat Waves						Increased air conditioning use, increased pavement maintenance
Temperature Responses	Warmer Soil Temperatures	Vegetation shifts toward species better adapted to warmer soil conditions	Vegetation shifts toward species better adapted to warmer soil conditions			Vegetation shifts toward species better adapted to warmer soil conditions	Increased vegetation growth leads to increased mowing/ landscaping requirements
Precipitation Responses	Winter and Early Spring Precipitation as Rain Instead of Snow	Shorter reliable low-flow maintenance or construction periods	Shorter reliable low-flow maintenance or construction periods			Reduced pollutant trapping effectiveness due to increased soil saturation during dormant season	
Precipitation Responses	Increased Rainfall During Frequent (such as 2-yr) Storm Events	Reduced effectiveness of Chapter 13 measures leading to increased bank instability	Increased detention pond pumping costs			Reduced effectiveness of volume reduction benefits	
Precipitation Responses	Increased Intensity and Frequency of Extreme Rain and Wind Events						Increased flood damage to buildings and equipment
Precipitation Responses	Increased Total Annual Precipitation					Increased volume of stormwater treated	
Precipitation Responses	Increased Occurrence of Summer Drought	Vegetation shifts toward species better adapted to drought conditions	Vegetation shifts toward species better adapted to drought conditions			Damage to planted vegetation	Damage to landscaping vegetation
Precipitation Responses	Increased Occurrence of Freezing Rain					Damage to vegetation due to increased road salting	Increased incidence of roof damage, increased need for deicers on sidewalks and parking lots
Subsurface Condition Responses	Higher Spring Recharge, Groundwater and Soil Moisture Levels	Increased incidence of slope failure	Increased incidence of slope failure			Decreased infiltration rates for biofilters, swales and raingardens	Increased basement seepage, foundation damage from swelling soils
Subsurface Condition Responses	Lower Late Summer Soil Moisture Levels	Vegetation shifts toward species better adapted to drier soil conditions Increased erosion potential	Vegetation shifts toward species better adapted to drier soil conditions			Vegetation shifts toward species better adapted to drier soil conditions	
Subsurface Condition Responses	Lower Late Summer Groundwater						
Subsurface Condition Responses	More Frequent Freeze-thaw Cycles	Increased erosion potential	Extended periods of soft ground limiting maintenance and construction activity				Increased pavement maintenance

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility

- High
- Moderate
- Low

Legend

DC - Diversion Chamber
DS - Diversion Structure
HQ - Headquarters
IS - Intercepting Structure
ISS - Inline Storage System
MIS - Metropolitan Interceptor Sewer
NSC - Near Surface Collector
WRF - Water Reclamation Facility

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Table 2-15. District Service Impact and MIS Physical Impact Vulnerability to Potential Receiving Water and Additional External Condition Climate Change Responses

		Service Impacts				Physical Impacts – MIS			
	Physical/External Responses to Climate Change	MIS/ISS	WRFs	Watercourses	Landfill Gas System	Pipes (1)	Manholes	Control Structures (2)	Pump Stations
Receiving Water Responses	Increased Lake Michigan Water Level	Reduced CSO outfall capacity	Reduced hydraulic efficiency of site drainage, increased effluent pumping	Increased watercourse water levels near lake					
Receiving Water Responses	Decreased Lake Michigan Water Level	Increased CSO volume due to reduced resistance at outfalls			Reduced turbine cooling water intake capacity	Increased scour at outfalls			
Receiving Water Responses	Warmer Lake Michigan Water Temperatures		Increased treatment due to perception of District's contribution to reduced water quality and/or increased algal growth Increased nitrification and impacts to other processes due to warmer wastewater, possibly requiring changes in operational strategies and increased aeration requirements		Increased volume of non-contact cooling water required for turbines	Increased wastewater corrosion potential due to warmer water supply	Increased wastewater odor and corrosion potential due to warmer water supply	Increased wastewater odor and corrosion potential due to warmer water supply	Increased wastewater odor and corrosion potential due to warmer water supply
Receiving Water Responses	Increased Pollutant Loads to Lake Michigan		Increased treatment due to perception of District's contribution to reduced water quality and/or increased algal growth						
Receiving Water Responses	Increased Watercourse Flow During Frequent (such as 2-year) Events	Reduced CSO outfall capacity							
Receiving Water Responses	Increased Watercourse Flow During Extreme (such as 100-year) Events	Increased CSO/SSO volume due to increased frequency of floodwater infiltration into wastewater system	Increased dilution of influent due to increased frequency of floodwater infiltration into wastewater system	Reduced flood management level of protection, higher regulatory flood elevations and expanded floodplains					
Receiving Water Responses	Lower Watercourse Base Flows/Levels								
Receiving Water Responses	Warmer Watercourse Flows				Increased volume of non-contact cooling water required for turbines				
Receiving Water Responses	Increased Pollutant Loadings from Watersheds		Increased treatment due to perception of District's contribution to reduced water quality						
Additional External Responses	Increases in External Energy Costs	Increased operational costs	Increased operational costs		Increased demand for energy from turbines				
Additional External Responses	Reduced Air Quality								
Additional External Responses	Demographic Shifts	System changes to serve changed demographics	Increased required treatment plant capacity						
Additional External Responses	Implementation of Water Conservation Measures	Reduced O&M revenue due to reduced volume serviced	Changes to treatment process effectiveness due to higher strength wastewater			Increased corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility
- High (red)
- Moderate (yellow)
- Low (green)

Legend

DC - Diversion Chamber
DS - Diversion Structure
HQ - Headquarters
IS - Intercepting Structure
ISS - Inline Storage System
MIS - Metropolitan Interceptor Sewer
NSC - Near Surface Collector
WRF - Water Reclamation Facility

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Table 2-16. District ISS and WRF Physical Impact Vulnerability to Potential Receiving Water and Additional External Condition Climate Change Responses

		Physical Impacts								
		ISS					WRFs			
	Physical/External Responses to Climate Change	Tunnel	Drop Shaft Systems	Access Shafts	Control Structures (3)	Inline Pump Station (4)	Unit Processes	Buildings	Pipelines (5)	Floodwalls
Receiving Water Responses	Increased Lake Michigan Water Level						Increased risk of floatation of buried tanks, construction and maintenance challenges due to higher groundwater	Increased basement seepage due to higher groundwater		Reduced effectiveness of flood protection measures
	Decreased Lake Michigan Water Level						Increased dry rot of exposed wooden pilings			
	Warmer Lake Michigan Water Temperatures	Increased wastewater corrosion potential due to warmer water supply	Increased wastewater odor and corrosion potential due to warmer water supply	Increased odor and corrosion potential wastewater due to warmer water supply	Increased wastewater odor and corrosion potential due to warmer water supply		Increased wastewater odor and corrosion potential due to warmer water supply			
	Increased Pollutant Loads to Lake Michigan									
	Increased Watercourse Flow During Frequent (such as 2-year) Events									
	Increased Watercourse Flow During Extreme (such as 100-year) Events									
	Lower Watercourse Base Flows/Levels									
	Warmer Watercourse Flows									
	Increased Pollutant Loadings from Watersheds	Increased sediment removal requirements								
Additional External Responses	Increases in External Energy Costs									
	Reduced Air Quality						Restrictions on emissions			
	Demographic Shifts									
	Implementation of Water Conservation Measures	Increased corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater	Increased odor and corrosion potential due to higher strength wastewater		Increased odor and corrosion potential due to higher strength wastewater			

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility	
High	(red)
Moderate	(yellow)
Low	(green)

Legend

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WRF - Water Reclamation Facility

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Table 2-17. District Watercourse, Landfill Gas System, Green Infrastructure and Other Buildings Physical Impact Vulnerability to Potential Receiving Water and Additional External Condition Climate Change Responses

	Physical/External Responses to Climate Change	Physical Impacts: Watercourses: Channels	Physical Impacts: Watercourses: Flood Management Facilities	Physical Impacts: Landfill Gas System: Pipeline	Physical Impacts: Landfill Gas System: Structures	Physical Impacts: Green Infrastructure	Physical Impacts: Other Buildings and Fleet (6)
Receiving Water Responses	Increased Lake Michigan Water Level						
Receiving Water Responses	Decreased Lake Michigan Water Level	Reduced hydraulic efficiency of flushing station intakes					
Receiving Water Responses	Warmer Lake Michigan Water Temperatures						
Receiving Water Responses	Increased Pollutant Loads to Lake Michigan						
Receiving Water Responses	Increased Watercourse Flow During Frequent (such as 2-year) Events	Increased bed/bank erosion and sediment transport	Increased debris removal frequency, including skimmer				
Receiving Water Responses	Increased Watercourse Flow During Extreme (such as 100-year) Events	Increased risk of overtopping or exceeding capacity	Increased risk of overtopping or exceeding capacity				
Receiving Water Responses	Lower Watercourse Base Flows/Levels	Reduced habitat, navigation and fish passage					
Receiving Water Responses	Warmer Watercourse Flows	Reduced ecological quality Increased flushing station operation					
Receiving Water Responses	Increased Pollutant Loadings from Watersheds	Reduced ecological quality, increased maintenance	Increased sediment and debris removal requirements			Increased maintenance requirements	
Additional External Responses	Increases in External Energy Costs		Increased detention pond pumping costs				Increased operational costs
Additional External Responses	Reduced Air Quality						Restrictions on emissions
Additional External Responses	Demographic Shifts						
Additional External Responses	Implementation of Water Conservation Measures						

(1) - Includes CSO/SSO outfalls and NSCs
(2) - Includes DC and IS structures
(3) - Includes DS structures
(4) - Includes head tanks
(5) - Includes WRF outfalls
(6) - Includes HQ, Lab, S. 13th Street, Conveyance Field Office

Magnitude of Impact on Service/Facility
- High
- Moderate
- Low

Legend
- DC - Diversion Chamber
- DS - Diversion Structure
- HQ - Headquarters
- IS - Intercepting Structure
- ISS - Inline Storage System
- MIS - Metropolitan Interceptor Sewer
- NSC - Near Surface Collector
- WRF - Water Reclamation Facility

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2.5 District Facility Risk Prioritization

The relative risk to the District for each of the individual impacts noted in Table 2-12 through Table 2-17 was determined by cross referencing the vulnerability level noted in those tables to the likelihood of the climate response in Table 2-2 through Table 2-6 (for the period 2014-2050) or in Table 2-7 through Table 2-11 (for the period 2014-2100) using Table 2-18. Matrices showing the results of these analyses for 2050 and 2100 are provided as Appendix B and Appendix C, respectively.

Table 2-18. Estimated Planning Risk Associated With Impacts of Climate Change Responses

Likelihood of Response	Planning Risk to Service/Facility		
High	Low	High	High
Moderate	Low	Moderate	High
Low	Low	Low	Moderate
	Low	Moderate	High
	District Facility Vulnerability to Climate Response		

2.5.1 Climate Change-Related Impacts Posing Greatest Risk to District Facilities, 2014- 2050

Based on the risk prioritization described above, the potential impacts in Table 2-19 are considered to pose the greatest concern to District services or facilities for the period 2014-2050:

Table 2-19. Highest Risk Climate Change Impacts, 2014-2050

System	Impact	Elements Affected	Response Driver(s)
MIS/ISS	Increased operational costs	System	Increases in external energy costs[1]
	Increased incidence of external power outages	MIS control structures, MIS pump stations, ISS control structures	Increased incidence of heat waves, (increased intensity of extreme rain and wind events)
	Overheated electronics in monitoring and control systems	MIS control structures, ISS control structures	Increased incidence of heat waves
	Increased corrosion potential	Pipes, manholes, MIS control structures, MIS pump stations, tunnel, drop shaft systems, access shafts, ISS control structures	Lower late summer groundwater, (Increased air temperatures, warmer Lake Michigan water temperatures, implementation of conservation measures)
	Increased odor potential	MIS control structures, MIS pump stations, drop shaft systems, access shafts, ISS control structures	Lower late summer groundwater, (Increased air temperatures, warmer Lake Michigan water temperatures, implementation of conservation measures)

Table 2-19. Highest Risk Climate Change Impacts, 2014-2050			
System	**Impact**	**Elements Affected**	**Response Driver(s)**
WRFs	Increased odor and corrosion potential	Unit processes	Lower late summer groundwater, (Increased air temperatures, warmer Lake Michigan water temperatures, implementation of conservation measures)
	Increased level of treatment due to perception of District's contribution to reduced water quality and/or increased algal growth	System	Warmer Lake Michigan water temperatures, increased pollutant loads to Lake Michigan, increased pollutant loadings from watersheds
	Increased operational costs	System	Increases in external energy costs
	Overheated electronics in monitoring and control systems	Unit processes	Increased incidence of heat waves[1]
Watercourses	Reduced flood management level of protection	System	Increased watercourse flow during extreme events
	Higher regulatory flood elevations and expanded floodplains	System	Increased watercourse flow during extreme events
	Vegetation shifts toward species adapted to warmer or drier conditions	Channels, flood management facilities	Increased air temperatures, warmer soil temperatures, lower late summer soil moisture levels (Increased occurrence of summer drought)
	Increased need for disease vector control	Channels, flood management facilities	Increased air temperatures
	Reduced Chapter 13 effectiveness leading to bank instability	Channels	Increased rainfall during frequent storm events
	Increased bed/bank erosion and sediment transport	Channels	Increased watercourse flow during frequent events
Other	Vegetation shifts toward species adapted to warmer or drier conditions	Green infrastructure	Increased air temperatures, warmer soil temperatures, lower late summer soil moisture levels
	Increased operational costs	Other Buildings	Increases in external energy costs

[1] *Although mitigation measures are being enacted, this currently poses a potential threat to District operations that could increase in the future.*

2.5.2 Climate Change-Related Impacts Posing Moderate Risk to District Facilities, 2014- 2050

Based on the risk prioritization described above, the potential impacts in Table 2-20 are considered to pose a moderate concern to District services or facilities for the period 2014-2050:

Table 2-20. Moderate Risk Climate Change Impacts, 2014-2050

System	Impact	Elements Affected	Response Driver(s)
WRFs	Increased dry rot on exposed wooden piles	Unit processes	Decreased Lake Michigan water level
	Restrictions on emissions	Unit processes	Reduced air quality
	Increased flood damage to buildings and equipment	Buildings	Increased intensity of extreme rain and wind events
Water-courses	Increased risk of overtopping or exceeding capacity	Channels, flood management facilities	Increased watercourse flow during extreme events
	Reduced habitat, navigation and fish passage	Channels	Lower watercourse base flows/levels
Landfill Gas System	Reduced turbine cooling water intake capacity	System	Decreased Lake Michigan water levels
	Increased demand for energy from turbines	System	Increases in external energy costs
Other	Increased flood damage to buildings and equipment	Other buildings	Increased intensity of extreme rain and wind events
	Restrictions on emissions	Other buildings (fleet)	Reduced air quality

2.5.3 Climate Change-Related Impacts Posing Low Risk to District Facilities, 2014- 2050

Based on the risk prioritization described above, the potential impacts are considered to pose a relatively low level of concern to District services or facilities for the period 2014-2050:

Table 2-21. Lowest Risk Climate Change Impacts, 2014-2050			
System	Impact	Elements Affected	Response Driver(s)
MIS/ISS	Increased CSO and SSO volume and frequency during winter and early spring	System	Winter and early spring precipitation as rain instead of snow, higher spring recharge, groundwater and soil moisture levels
	Increased CSO volume and frequency	System	Increased rainfall during frequent storm events, increased intensity of extreme rain and wind events
	Reduced CSO outfall capacity	System	Increased Lake Michigan water level, increased watercourse flow during frequent events
	Increased CSO volume due to reduced resistance at outfalls	System	Decreased Lake Michigan water level
	Increased CSO and SSO volume due to increased frequency of floodwater infiltration into wastewater system	System	Increased intensity of extreme rain and wind events
	System changes to serve changed demographics	System	Demographic shifts
	Reduced O&M revenue due to reduced volume serviced	System	Implementation of conservation measures
	Increased incidence of external power outages	ISS pump station	Increased incidence of heat waves, increased intensity of extreme rain and wind events
	Shorter reliable low-flow maintenance or construction periods	MIS control structures, MIS pump stations, tunnel, drop shaft systems, access shafts, ISS control structures, inline pump station	Winter and spring precipitation as rain instead of snow
	Increased operation, wear and tear	Inline pump station	Winter and early spring precipitation as rain instead of snow, increased total annual precipitation, higher spring recharge, groundwater and soil moisture levels
	Increased operation, wear and tear	MIS pump stations	Increased total annual precipitation, higher spring recharge, groundwater and soil moisture levels
	Extended periods of soft ground limiting maintenance and construction activity	Pipes, manholes, control structures, pump stations	More frequent freeze-thaw cycles

Table 2-21. Lowest Risk Climate Change Impacts, 2014-2050			
System	Impact	Elements Affected	Response Driver(s)
	Increased scour at outfalls	Pipes	Decreased Lake Michigan water level
	Increased sediment removal requirements	Tunnel	Increased pollutant loading loadings from watersheds
WRFs	Increased nitrification and other processes due to warmer wastewater, possibly requiring changes in operational strategies and increased aeration requirements	System	Increased air temperatures, warmer Lake Michigan water temperatures
	Increased incidence of external power outages	System	Increased incidence of heat waves, increased intensity of extreme rain and wind events
	Reduced biological treatment and settling process efficiency	System	Winter and early spring precipitation as rain instead of snow, higher spring recharge, groundwater and soil moisture levels
	Increased treatment plan operations attention	System	Increased intensity of extreme rain and wind events
	Low-flow treatment challenges	System	Increased occurrence of summer drought
	Increased volume of wastewater treated	System	Increased total annual precipitation
	Changes to treatment process effectiveness due to higher strength wastewater	System	Lower late summer groundwater, implementation of conservation measures
	Reduced hydraulic efficiency of site drainage	System	Increased Lake Michigan water level
	Increased effluent pumping	System	Increased Lake Michigan water level
	Increased dilution of effluent due to increased frequency of floodwater infiltration into wastewater system	System	Increased watercourse flow during extreme events
	Increased required treatment plant capacity	System	Demographic shifts
	Shorter reliable low-flow maintenance or construction periods	Unit processes, pipelines	Winter and early spring precipitation as rain instead of snow

Table 2-21. Lowest Risk Climate Change Impacts, 2014-2050			
System	Impact	Elements Affected	Response Driver(s)
	Increased risk of floatation of buried tanks	Unit processes	Higher spring recharge, groundwater and soil moisture levels, increased Lake Michigan water level
	Extended periods of soft ground limiting maintenance and construction activity	Unit processes	More frequent freeze-thaw cycles
	Construction and maintenance challenges due to higher groundwater	Unit processes	Increased Lake Michigan Water level
	Increased air conditioning use	Buildings	Increased air temperatures, increased incidence of heat waves
	Increased maintenance of asphalt roofs	Buildings	Increased air temperatures
	Increased pavement maintenance	Buildings	Increased incidence of heat waves, more frequent freeze-thaw cycles
	Increased incidence of roof damage	Buildings	Increased occurrence of freezing rain
	Increased need for deicers on sidewalks and parking lots	Buildings	Increased occurrence of freezing rain
	Increased basement seepage	Buildings	Higher spring recharge, groundwater and soil moisture levels, increased Lake Michigan water level
	Reduced effectiveness of flood protection measures	Floodwalls	Increased Lake Michigan Water level
Water-courses	Increased watercourse water levels near lake	System	Increased Lake Michigan Water level
	Increased incidence of slope failure	Channels, flood management facilities	Higher spring recharge, groundwater and soil moisture levels
	Shorter reliable low-flow maintenance or construction periods	Channels, flood management facilities	Winter and early spring precipitation as rain instead of snow
	Increased erosion potential	Channels	Lower late summer soil moisture levels, more frequent freeze-thaw cycles
	Extended periods of soft ground limiting maintenance and construction activity	Flood management facilities	More frequent freeze-thaw cycles

Table 2-21. Lowest Risk Climate Change Impacts, 2014-2050			
System	Impact	Elements Affected	Response Driver(s)
	Increased detention pond pumping costs	Flood management facilities	Increased rainfall during frequent events, increased external energy costs
	Increased debris removal frequency, including skimmer	Flood management facilities	Increased watercourse flow during frequent events
	Reduced ecological quality	Channels	Warmer watercourse flows, increased pollutant loadings from watersheds
	Reduced hydraulic efficiency of flushing station intakes	Channels	Decreased Lake Michigan water level
	Increased flushing station operation	Channels	Warmer watercourse flows
	Increased maintenance, sediment and debris removal requirements	Channels, flood management facilities	Increased pollutant loading loadings from watersheds
Landfill Gas System	Reduced energy production by turbines	System	Increased air temperatures
	Increased volume of non-contact cooling water required for turbines	System	Increased air temperatures, warmer watercourse flows, warmer Lake Michigan water temperatures
	Increased landfill gas production exhausting supply more quickly	System	Warmer soil temperatures
Other	Reduced pollutant trapping effectiveness due to increased soil saturation during dormant season	Green Infrastructure	Winter and early spring precipitation as rain instead of snow
	Reduced effectiveness of volume reduction benefits	Green Infrastructure	Increased rainfall during frequent storm events
	Increased volume of stormwater treated	Green Infrastructure	Increased total annual precipitation
	Damage to planted vegetation	Green Infrastructure	Increased occurrence of summer drought
	Damage to vegetation due to increased road salting	Green Infrastructure	Increased occurrence of freezing rain

Table 2-21. Lowest Risk Climate Change Impacts, 2014-2050			
System	Impact	Elements Affected	Response Driver(s)
	Decreased infiltration rates for biofilters, swales and rain gardens	Green Infrastructure	Higher spring recharge, groundwater and soil moisture levels
	Increased maintenance requirements	Green Infrastructure	Increased pollutant loading loadings from watersheds
	Increased air conditioning use	Other Buildings	Increased air temperatures, increased incidence of heat waves
	Increased maintenance of asphalt roofs	Other Buildings	Increased air temperatures
	Increased pavement maintenance	Other Buildings	Increased incidence of heat waves, more frequent freeze-thaw cycles
	Increased mowing/landscaping requirements	Other Buildings	Warmer soil temperatures
	Damage to landscaping vegetation	Other Buildings	Increased occurrence of summer drought
	Increased incidence of roof damage	Other Buildings	Increased occurrence of freezing rain
	Increased need for deicers on sidewalks and parking lots	Other Buildings	Increased occurrence of freezing rain
	Increased basement seepage	Other Buildings	Higher spring recharge, groundwater and soil moisture levels
	Foundation damage from swelling soils	Other Buildings	Higher spring recharge, groundwater and soil moisture levels

2.5.4 Additional Climate-Related Risks, 2050-2100

The analysis for the period 2014-2100 generally provided the same level of risk prioritization as identified for the period 2014-2050. The exceptions are three additional high-risk impacts (Table 2-22):

Table 2-22. Additional Risks for 2050-2100	
Impact	**Element**
High risk of power outages due to increased intensity of extreme rain and wind events	MIS control structures, MIS pump stations, ISS control structures
High risk of flood damage to buildings and equipment due to increased intensity of extreme rain and wind events	WRF buildings, other buildings
High risk of vegetation shifts toward species adapted to drought conditions	Watercourse channels and flood management facilities

2.6 Climate Change Risk Adaptation

Potential climate change presents infrastructure managers with a situation where projected changes could have a significant effect on facilities and operations, yet where the probability and the magnitude of these changes are not known with a high degree of certainty. To manage its infrastructure system most prudently, the District must determine a course that makes appropriate investments to address the issues that pose the greatest threat while identifying those investments that may not be needed immediately but may become necessary if future changes progress. In developing adaptation plans for these uncertain conditions, infrastructure agencies often turn to some combination of two types of actions:

- Activities that will provide multiple benefits including reduction of climate change impacts and that will increase the resilience of operations regardless of whether projected climate changes occur, referred to as “no-regrets actions”
- Actions undertaken with the primary, or sole, purpose of addressing the impacts of projected climate change, referred to as “adaptation actions”

The following sections outline potential “no-regrets” activities and adaptation actions for the impacts identified as posing either a high or moderate risk to District facilities and operations.

2.7 “No Regrets” Activities and Adaptation Actions

“No regrets” activities and adaptation actions were identified for the high- and moderate-risk potential impacts (Table 2-23 and Table 2-24). “No regrets” activities are changes that could be incorporated into existing District procedures that would provide benefits regardless of the magnitude of climate change that eventually occurs. Adaptation actions are infrastructure or operational investments specifically targeted at climate change impacts, so there may be little or no value to implementing them before the risk of the impact is high enough to justify them. For that reason “triggers” have been identified for these actions and represent the threshold at which the investment becomes justified.

Table 2-23. “No Regrets” Activities and Adaptation Actions for High-Risk Impacts			
Impact	**“No Regrets” Activities**	**Adaptation Actions**	**Adaptation Trigger**
Increased MIS/ISS operational costs	Install more energy efficient equipment as equipment is replaced Maximize use of onsite-generated power for ISS Pump Station	Replace MIS pump stations with gravity systems as determined feasible by life cycle evaluations of potential redesigns	Cost-effectiveness as determined by feasibility study (See suggested next steps)
Increased incidence of external power outages at MIS control structures, MIS pump stations, ISS control structures	Confirm that all critical structures have adequate backup power. Confirm that procedures are in place that will allow backup power to be used without interruption to services. Upgrade backup power, if necessary.	None in addition to no-regrets activities	- - -
Overheated electronics in monitoring and control systems at MIS control structures, ISS control structures and WRFs	Invest in control technologies that are less sensitive to excessive temperatures or adopt a “run to failure” strategy with adequate system backups in place	Increase ventilation and/or insulation of critical electronic equipment	Temperatures exceed thresholds established for equipment operation
Increased treatment due to perception of District’s contribution to reduced water quality and/or increased algal growth	Continue interaction with community, USGS, universities and regulatory agencies to maintain situational awareness of potential changes	Conduct or support water quality studies to ensure causes of the problems are properly identified Continue long-term and active research partnership with USGS Adjust processes and practices to comply with revised limits Initiate pollutant trades	Permit revisions enacted
Increased odor and corrosion potential in MIS/ISS and WRF facilities	As sewer or force main replacements or linings occur, consider material resistant to hydrogen sulfide (H_2S)	Implement odor control measures and protect concrete surfaces	Confirmation of trend of increased H_2S sulfide concentrations
Increased WRF operational costs	Implement energy reduction strategies Change processes/ equipment to minimize exposure to energy costs as processes/equipment are upgraded	Change processes/ equipment to minimize exposure to energy costs	Cost-effectiveness as determined by feasibility study (See suggested next steps)
Reduced flood management level of protection	Consider incremental cost of incorporating potential flow increases into design of new flood management projects. Maximize implementation of green infrastructure practices.	Retrofit projects based on increasing flow trends	Hydrologic study indicating flow increases or increased regulatory flows issued by FEMA

Table 2-23. "No Regrets" Activities and Adaptation Actions for High-Risk Impacts

Impact	"No Regrets" Activities	Adaptation Actions	Adaptation Trigger
Higher regulatory flood elevations and expanded floodplains	Consider incremental cost of incorporating potential flow increases into design of new flood management projects. Maximize implementation of green infrastructure practices. Consider requiring new development and re-development to use increased precipitation when sizing BMPs Continue funding long-term flow and stage gaging stations with USGS/SEWRPC	Retrofit projects based on increasing flow trends Revision of Chapter 13	Hydrologic study indicating flow increases or increased regulatory flows issued by FEMA Regional acceptance of NOAA Atlas 14 precipitation data
Vegetation in channels and flood management facilities shifts toward species adapted to warmer or drier conditions	Develop species mix for projects with consideration of acceptable vegetation performance under (a) warmer or drier future conditions and (b) salt tolerance	Increase maintenance to prevent unacceptable vegetation performance	Observation of vegetation stress
Increased need for disease vector control in channels and flood management facilities	Analyze areas with potential to generate West Nile, Lyme Disease and other potential vectors. Develop vector control plan. Update regularly.	Conduct additional vector control activities on District properties	Observation of increased or unacceptable levels of vectors
Reduced Chapter 13 effectiveness leading to watercourse bank instability	Implementation of green infrastructure in areas or developments where mitigation not required under Chapter 13	Increase bank reinforcement along District watercourses	Confirmation of increased flow erosiveness by observation or model studies
Increased watercourse bed/bank erosion and sediment transport	Implementation of green infrastructure in areas or developments where mitigation not required under Chapter 13	Increase reinforcement levels along District watercourses, increase annual sediment removal activities	Confirmation of increased sediment transport or deposition by observation or model studies
Green infrastructure vegetation shifts toward species adapted to warmer or drier conditions	Develop species mix for projects with consideration of acceptable vegetation performance under (a) warmer or drier future conditions and (b) salt tolerance	Increase maintenance to prevent unacceptable vegetation performance	Observation of vegetation stress
Increased building operational costs	Implement energy reduction strategies, install more energy efficient equipment as equipment is replaced	Budget for increased costs if they cannot be avoided by energy reduction strategies	Comparison of year-to-year energy expenditures

Table 2-24. "No Regrets" Activities and Adaptation Actions for Moderate-Risk Impacts			
Impact	"No Regrets" Activities	Adaptation Actions	Adaptation Trigger
Restrictions on emissions for mechanical operations, fleet, etc.	Incorporate low emission technology when upgrading facilities/fleet Incorporate energy-efficient designs during upgrades	Retrofit to reduce emissions	EPA requirement
Increased dry rot on exposed District facility wooden piles	As 2050 Facilities Plan considers District facilities, ensure that replacement of facilities on piles is evaluated.	Reinforce pilings or artificially increase local groundwater levels to submerge piles	Confirmation of trend of lower lake level that would expose piles
Increased flood damage to buildings and equipment	Incorporate floodproofing measures into upgrades where appropriate	Conduct site improvements to increase level of protection	Rainfall records indicate unacceptable increase in probability of flood damage
Increased risk of overtopping or exceeding capacity of District constructed flood management facilities	- - -	Reconstruct channels or retrofit flood management structures	Risk of damage due to overtopping justifies the cost of retrofit
Reduced habitat, navigation and fish passage	Incorporate habitat diversity and resiliency of function within designs	Reconstruct channels to provide narrower low-flow insets	Lost benefits are deemed to justify the cost of reconstruction
Reduced turbine cooling water intake capacity	- - -	Construct redesigned intakes and/or pumping system	Confirmation of trend of lower lake level to level that would adversely affect operability and costs justified by energy produced
Increased demand for energy from turbines	Reduce energy usage in operations	Increase turbine use to the extent possible and/or add turbine generating capacity	Energy costs less to produce than purchasing on the open market

2.8 Suggested Next Steps

The following steps are recommended as a prudent response to the risk of climate change as determined in this study:

- Undertake “no-regrets” actions as appropriate within current District operations
- Maintain situational awareness of regulatory agency policies that may affect discharge permit conditions
- Maintain situational awareness of potential floodplain reanalysis and remapping
- Evaluate feasibility of modification and develop cost-effective point for the following:
  - Replacement of MIS pump stations with gravity systems to reduce cost of operations
  - Electronic equipment retrofit to provide insulation and ventilation sufficient to mitigate increased air temperatures/heat waves
  - Replacement of WRF equipment to reduce cost of operations
- On an annual basis, compile monitoring data by the District and others and evaluate trends for the following:
  - Energy costs
  - Incidence of power outages
  - Air temperatures
  - Wastewater temperatures in MIS
  - H2S concentration in MIS
  - Lake level
  - Dissolved oxygen in the estuary (real-time monitoring stations in estuary)
- Develop a vector management plan that includes monitoring activities, as appropriate
- Every five years analyze District rain gauge data to investigate trends in rainfall/storm intensity, annual rainfall volumes and frequency
- Specifically track changes in vegetation stress, vegetation communities, sediment deposition and scour through observations during annual inspections

Additionally, with every facilities plan update, the items determined in this study should be reevaluated to determine if additional potential impacts have arisen or if the nature of the risk is better understood. Based on this reevaluation, additional opportunities to institute “no-regrets” activities may be identified and the need for adaptation actions may prove to be more pressing.

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Section 3:

Conveyance System Impacts

The District's conveyance system is a network of green infrastructure, pipes, storage tunnels, and pumps and ancillary facilities used to convey wastewater from its satellite municipalities to the water reclamation facilities (WRF). The primary elements of the conveyance system are the metropolitan interceptor sewers (MIS), the inline storage system (ISS), and the Northwest Side Relief Sewer (NWSRS). The conveyance system is operated to provide a high level of service to the satellite municipalities while reducing the risk of combined and separate sewer overflows (CSOs and SSOs, respectively).

Municipalities in the District planning area are subdivided into sewershed areas, that are further grouped into metershed areas. During the District's 2020 Facilities Plan (Milwaukee Metropolitan Sewerage District, June 2007), the planning area was divided into 207 metersheds. Metershed areas are defined based on the flow monitoring system that is used to measure flows in the MIS and in the municipal sewers that are tributary to the MIS. Metersheds in the planning area are classified into two groups: terminal metersheds and incremental metersheds. A terminal metershed has a unique tributary area with one flow meter at the downstream end and no upstream meters. An incremental metershed is one where there is at least one upstream flow meter in addition to the flow meter at the downstream end. The tributary area between the upstream and downstream meters is called an incremental metershed. Within the service area, there are 158 terminal metersheds and the rest are incremental metersheds. This study only evaluated the terminal metersheds and did not include the incremental metersheds. In addition, the simulations focused on ultimate, build-out conditions of these metersheds. The population and land use values for the ultimate, build-out condition were prepared by SEWRPC for the District's 2020 Facilities Plan.

This section contains the results of the evaluation of the conveyance system performance in response to the various climate change scenarios. The conveyance system performance is quantified as:

- SSO frequency and volume
- CSO frequency and volume
- Metershed peak flow recurrence intervals

Four climate change scenarios were evaluated in addition to a baseline case, as summarized in Table 3-1.

Table 3-1. Climate Change Scenarios		
Model Scenario	**Climate Forecast Horizon**	**Climate Change Severity**
Baseline	Existing climate conditions based on historic record (1940-2004)	
CM-s10	Mid-Century	Moderate Change; 10% Downscaled Network
CM-s90	Mid-Century	Larger Change; 90% Downscaled Network
CE-s10	End-of-Century	Moderate Change; 10% Downscaled Network
CE-s90	End-of-Century	Larger Change; 90% Downscaled Network

Each climate change scenario has a different precipitation and temperature time series to characterize an alternative climate pattern. The time series were developed by the meteorological team at UW-Madison and provided to Brown and Caldwell for use in this evaluation.

A baseline scenario was established to represent the existing climate conditions. This scenario was based on the actual precipitation and temperature readings from the National Weather Service station at General Mitchell International Airport in Milwaukee, WI. The 64.5-year period in the historic record from 1/1/1940 to 6/30/2004 was the basis of this evaluation. (This is the same evaluation period used in the 2020 Facilities Plan and the McLellan climate change study.)

The model scenario names used in this report are abbreviated names to concisely identify the scenarios. Two of the scenarios used a mid-century climate forecasting horizon and the other two scenarios used an end-of-century forecast horizon. For each forecast horizon, there are two scenarios to envelop the performance: a 10% downscaled network and a 90% downscaled network.

The climate change scenarios were generated by statistically downscaling the global climate change modeling results to create data sets that represent local conditions. The 10% and 90% descriptions are not specific measures of change for any one variable. Instead they are general descriptions of severity to indicate whether a scenario is a moderate change (10% case) or a more extreme change (90% case). The 90% scenarios for mid-century and end-of-century cases are not the most extreme model cases, but they are scenarios that have more than average change. Further details on the downscaling method and the climate change scenarios can be found in the McLellan climate change study.

Temperature and precipitation are the fundamental data defining the climate scenarios. An evaporation time series was developed based on the temperature and precipitation time series. All of the other climatological parameters were assumed to be unchanged for all scenarios.

3.1 Approach

Two approaches were used to evaluate the impacts of climate change on the conveyance system. The first approach evaluated the response of the overall District system. In this approach the large scale performance was quantified using overflow frequencies and volume. In the second approach, the evaluation focused on individual metersheds, quantifying the response using the recurrence interval of the peak wet weather metershed flows. These two approaches were useful to test the large- and small-scale responses of the conveyance system to different climate scenarios.

The methodology and tools used for the conveyance system evaluation are briefly described in the following subsections before discussing the results of the two approaches.

3.1.1 Methodology

A number of numeric models were used in this evaluation that were used in previous projects for the District. For this evaluation, there were no modifications to any of the model parameters or calibrations. With the exception of the baseline scenario models (which had no changes), only the precipitation, temperature, and evaporation input time series were changed to represent the climate scenarios.

Simulation results from the McLellan climate change study were used for the mid-century scenarios. The end-of-century scenarios were simulated using the rainfall and temperature data that was provided by the District for this evaluation. The methods used for these two studies were similar, but not identical in all aspects. In particular, the format of the precipitation data had a 15-minute time step in the baseline and mid-century scenarios and the format of the end-of-century precipitation data was a one-hour time step. The sensitivity to the choice of time step was checked and the results were found to be essentially equal. The numerical differences were insignificant and the choice of time step does not alter the interpretation of the results.

None of these models explicitly address the impact of frozen ground on conveyance system flows.

3.1.2 Models

The main models that were used for the evaluation of the climate change impacts on the conveyance system were:

- Hydrologic Simulation Program – FORTRAN (HSPF)
- Flow Forecasting System (FFS)
- MACRO (MACRO is a flow accounting model used to perform long-term continuous simulations of the operation of the major components of the District conveyance, storage, and treatment system.)

3.1.2.1 HSPF – Hydrologic Simulation Program FORTRAN

The HSPF model simulates the general hydrologic environment in which the sewer system exists. HSPF is a continuous hydrologic model that simulates the groundwater infiltration, interflow, and surface runoff response to precipitation and other meteorological data. The full featured hydrology of the model includes the effect of antecedent moisture conditions in the ground (from previous storms or snow melt conditions) to create continuous simulation results that span a long period of time. Simulation results from HSPF were used as input to the MACRO and Flow Forecasting System (FFS) models.

3.1.2.2 FFS – Flow Forecasting System

The FFS model uses output from the HSPF model to generate flows for the conveyance system. FFS establishes the base sanitary flow and base ground infiltration for each metershed. The infiltration and inflow (I/I) components of the flow are estimated by applying scaling factors (which act as calibration parameters) to the hydrologic results of the HSPF simulations.

One of the advantages of the FFS program is the freedom to simulate flows for long periods of time. The long-term simulation results in HSPF were used by FFS to generate long-term simulated records of wastewater flow for each metershed in the District service area. For each climate change scenario, the flow frequency analysis was applied to the 64.5 year record of simulated flows for each metershed. The flow frequency analysis used the Log-Pearson Type III distribution to estimate peak hourly flow rates for the 1-, 2-, 5-, 10-, 20-, 50-, and 100-year recurrence intervals. The results of the climate change scenarios were compared to the baseline scenario by comparing the change in the recurrence interval curves.

3.1.2.3 MACRO

The MACRO model is a water balance representation of the District conveyance and storage system that computes the frequencies and volumes of CSOs and SSOs related to the operations of the ISS. The HSPF hydrologic results were loaded into the MACRO model to simulate the generation of flow in the sanitary and combined sewer systems. MACRO simulations account for the volume of flow treated by the WRFs, stored in the ISS, and overflowing as CSOs and SSOs.

Key objectives of the climate change MACRO analysis were to:

- Simulate long-term hydrologic conditions in response to changing precipitation and temperature scenarios as a result of climate change
- Simulate the long-term response of the District system to SSO and CSO frequencies and volumes in response to changing climate scenarios

The facilities that were included in the MACRO model represent the existing District conveyance and treatment facilities in operation as of December 31, 2013. The operations of the District system were modeled using typical operating parameters. Table 3-2 summarizes the essential operating parameters that were used to configure the MACRO model. Based on current operating strategies, the volume reserved for separate sewer inflow (VRSSI) was assumed to be a constant value of 232 MG for all events. This means that the ISS may store up to 200 MG of flow from the combined sewer system, after which time the remaining 232 MG was reserved to store excess flow from the separate sanitary sewer area. All of the climate scenarios used the same MACRO parameters; only the input HSPF files varied from scenario to scenario.

Table 3-2. MACRO Parameters

Operational Parameter	Model Value
ISS volume	432 MG
VRSSI	232 MG
Jones Island WRF treatment	330 mgd
Jones Island combined sewage treatment	No combined sewage treatment in most cases; one baseline alternative case used 60 mgd of combined sewage treatment.*
South Shore WRF treatment	300 mgd
ISS Pump to Jones Island	140 mgd
ISS Pump to South Shore	40 mgd

**– 60 mgd was used because this was the previously allowed limit; current District operating permit allows peak combined sewage treatment rate of 100 mgd.*

Combined sewage treatment is a practice used at the Jones Island WRF during some extreme wet weather events whereby a portion of the flow receives primary treatment and disinfection, but not secondary treatment, in order to maximize the volume of flow treated and minimize overflows and the potential for basement backups. Initially combined sewage treatment at the Jones Island WRF was not utilized in any of the simulations for this study. (This is a significant departure from previous studies, such as the District's 2020 Facilities Plan or the McLellan climate change study, both of which assumed combined sewage treatment in the evaluations.) While the baseline case and the climate change cases did not use combined sewage treatment, one additional case (using the baseline climate conditions) with combined sewage treatment was added to the evaluation to show the changes in the results as a result of allowing combined sewage treatment. Combined sewage treatment helps to reduce overflows by increasing the volume treated by the Jones Island WRF.

3.2 Overflow Frequency and Volume

The MACRO model is a screening-level model that produces simulation results that are useful to study the impact of various system-wide changes on the overall response of the District system. The MACRO model was developed to simulate the District system response quickly over a long simulation period using fundamental water balance principles. Therefore, MACRO is well suited to this study because it can show relative changes to the overall conveyance system.

The MACRO model simulated ISS-related overflows from the District system. ISS-related overflows are the largest source of wastewater overflows in the District service area. Other overflows that are not related to the ISS, such as SSOs from the local conveyance systems and overflows from the District system that are caused by restrictions in the conveyance system, are not included in the MACRO model; however, these other sources of overflows are relatively small compared to the ISS-related overflows.Model results should not be interpreted as rigorously accurate model predictions. The absolute values of simulated overflow volumes or the frequency of overflows should be interpreted from the perspective of the intended level of model accuracy. This is particularly true of the simulated frequency of ISS-related SSO events because they are relatively rare in the 64.5-year period. For example, in the baseline case, the ISS-related SSO frequency would be 0.56 events per year because there would be only 36 events in the 64.5 year simulation period. The model results are best used to observe changes from the baseline and evaluate the sensitivity to climate inputs. A rigorous estimation of SSO level of protection was not the objective of this study.

Table 3-3 contains a summary of the average annual frequency and volume of overflows as simulated by the MACRO model. The table also contains a summary of climate conditions: average annual temperature, precipitation, maximum rainfall intensity of the most intense hourly rainfall value (for the August 1986 event) in the period of record, and average annual potential evapotranspiration (PET). The average annual precipitation did not vary significantly between climate scenarios. For large events, the peak rainfall intensities were significantly greater than those of the baseline scenario, even though the average annual precipitation amounts were only slightly higher. Overall, the most noticeable change in the climate variables was the substantial increase in PET.

Figure 3-1 contains graphs of the results of Table 3-3 in bar charts for CSO and SSO frequency. The climate change scenarios had less frequent SSOs and more frequent CSOs as compared to the baseline case; however, these changes were not large. For example, the baseline CSO frequency of 4.11 events per year increased to 4.51 events per year in the End-of-Century 90% (CE-s90) scenario. The SSO frequency was 0.56 events per year in the baseline case but decreased to 0.45 events per year in the CE-s90 scenario.

Figure 3-1 also shows the decrease in overflows when combined sewage treatment was used in the simulations. With a combined sewage treatment limit of 60 mgd, the CSO frequency decreased to 3.77 events per year and the SSO frequency decreased to 0.48 events per year. Combined sewage treatment is helpful to reduce the risk of overflows. As a result, the increase in CSOs due to climate change might be mitigated by the use of combined sewage treatment because the relative increase due to climate change is similar to the relative decrease due to combined sewage treatment. Although not modeled, the use of combined sewage treatment to the limit of 100 mgd would likely result in a further decrease in CSO and SSO frequency and volume because a greater volume of wastewater could be treated.

Figure 3-2 shows the following average annual volumes:

- Collected in the MIS
- Treated at the Jones Island and South Shore WRFs
- Overflowing as SSOs and CSOs

Approximately 99% of all flow was treated in the simulations. The overflows were approximately 1% of the annual volume of flow in the system and the SSO volume attributed to ISS capacity limitations was only 0.015% of the total volume of flow in the system.

Figure 3-3 is similar to Figure 3-2, but each component of flow is represented as a percentage of the baseline value. In this format, the change from the baseline value was more clearly presented, especially for the CSO and SSO volumes that were so small in Figure 3-2. For the CE-s90 case, the average annual CSO volume increased 27% and the average annual SSO volume decreased 25% as compared to the baseline scenario.

Table 3-3. MACRO Simulation Results						
Scenario	Baseline with Combined Sewage Treatment	Baseline without Combined Sewage Treatment	CM-s10	CM-s90	CE-s10	CE-s90
Temperature						
Average Annual Temperature (degrees F)	46.6	46.6	52.3	55.3	54.7	59.6
Precipitation						
Average Precipitation Depth (inches/year)	31.8	31.8	32.5	32.8	33.1	32.9
Max Hourly Intensity (inches/hour); August 1986 event	3.06	3.06	2.90	3.94	3.00	3.47
Potential Evapotranspiration						
Average Annual PET (inches/year)	29.1	29.1	36.5	41.2	39.9	47.1
Average Annual Overflow Volumes						
ISS-related SSO (MG/year)	113	144	87	108	90	108
ISS-related CSO (MG/year)	932	983	961	1156	1015	1253
Total Overflow (MG/year)	1045	1127	1048	1264	1104	1361
Average Annual Overflow Frequencies						
ISS-related SSO Frequency (events/year)	0.48	0.56	0.45	0.48	0.43	0.45
ISS-related CSO Frequency (events/year)	3.77	4.11	3.91	4.42	4.19	4.51
Average Annual Volume Treated at WRF						
Treated at Jones Island WRF (MG/year)	37,700	37,500	36,700	36,200	36,600	35,800
Treated at South Shore WRF (events/year)	55,400	55,500	53,800	52,500	53,100	51,400

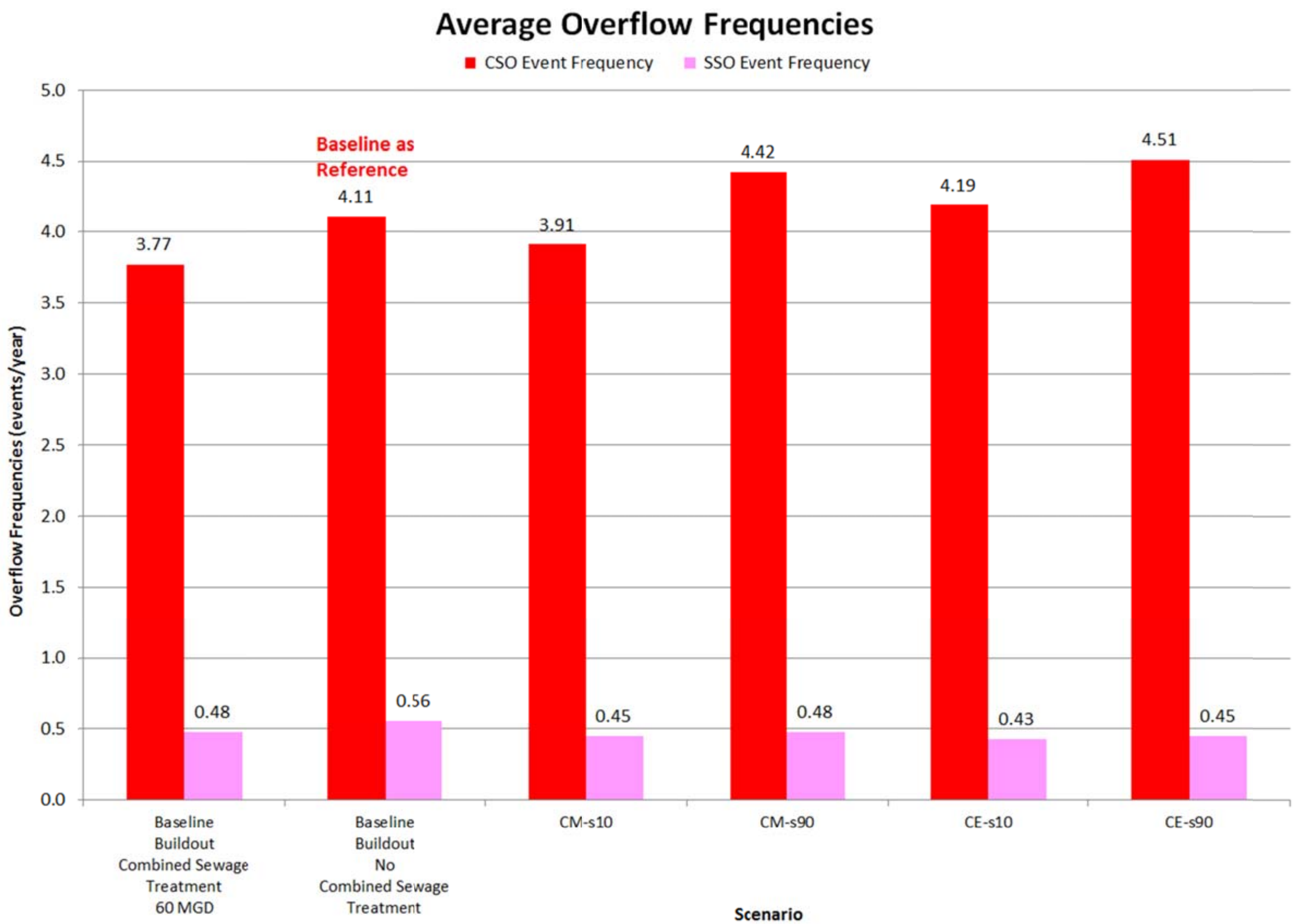

Figure 3-1. Average Annual Simulated Overflow Event Frequency Metershed Flows

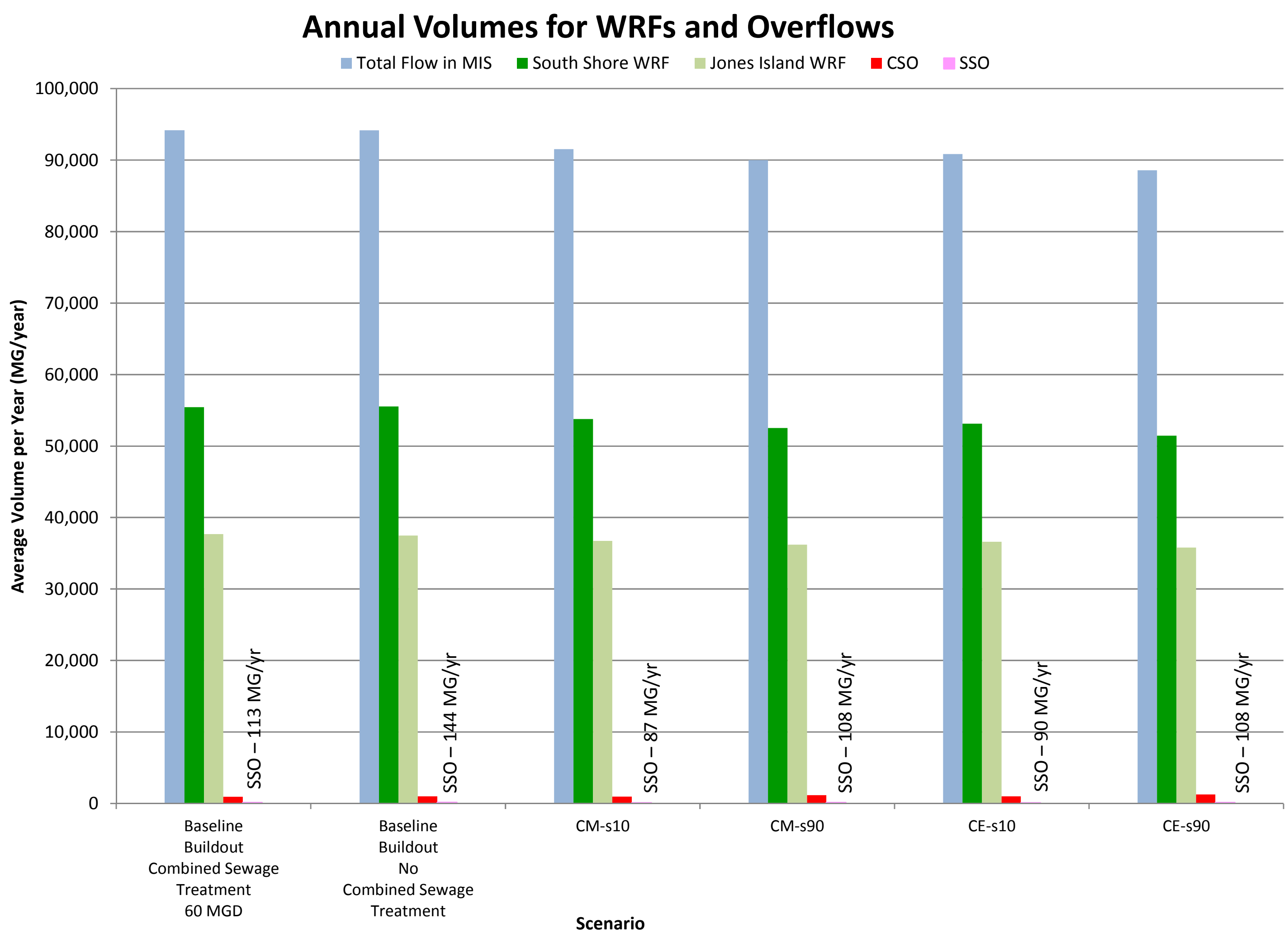

Figure 3-2. Average Annual Simulated Volumes

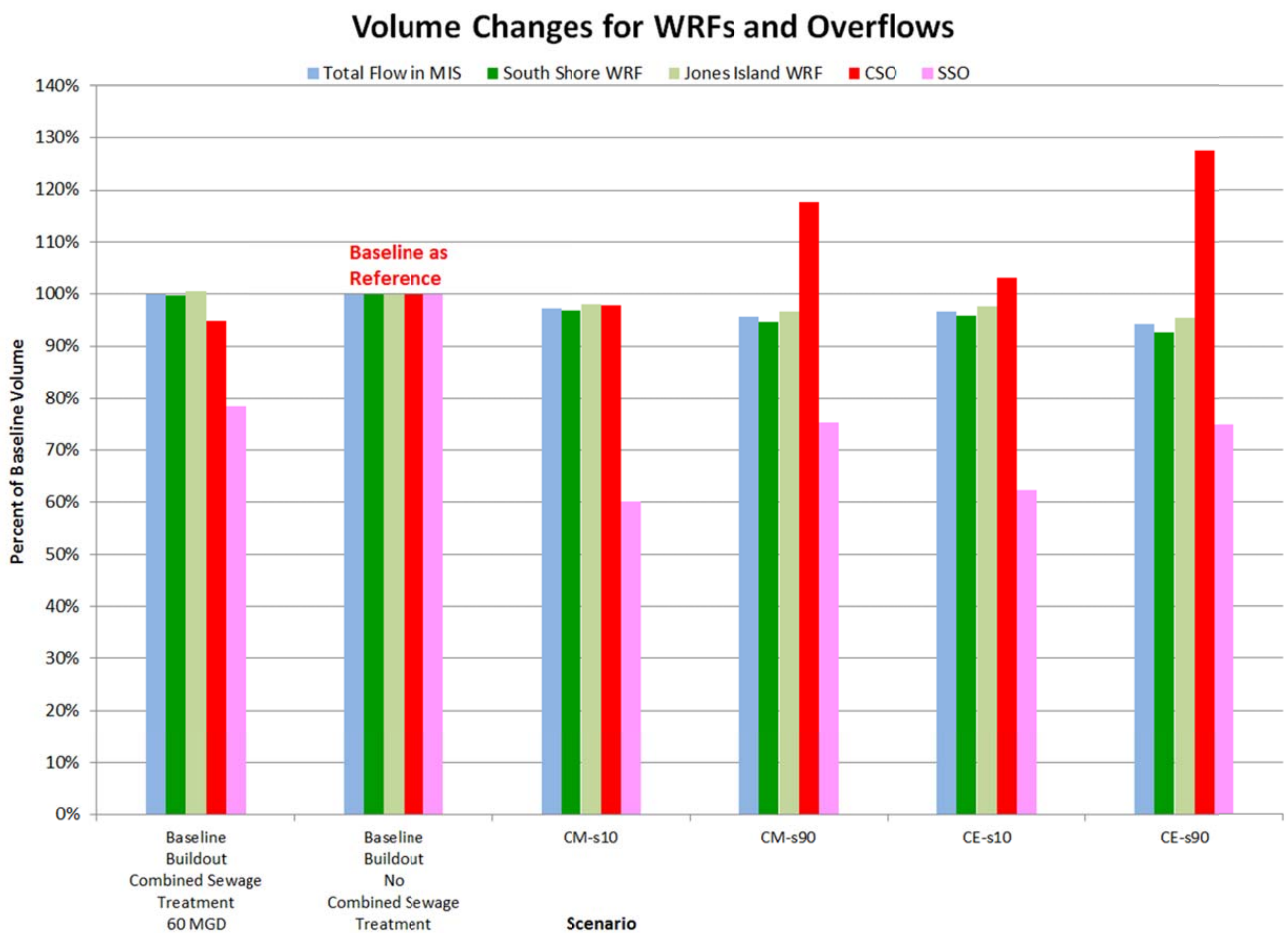

Figure 3-3. Percent of Baseline Volumes

The analysis was extended to study the climate change effects month by month. For this analysis, the CE-s90 case was compared to the baseline case without combined sewage treatment to envelop the conditions. Only the baseline and CE-s90 scenarios are shown in Figures 3-4 and 3-5.

Figure 3-4 shows the monthly overflow event frequencies. For each month, there are two bars for CSOs: the first bar is the baseline scenario and the second bar is the CE-s90 scenario. Similarly there are two bars for the monthly SSO event frequencies.

With the CE-s90 scenario, the CSO frequency increases from 4.11 to 4.51 events per year annually. Most simulated CSO events occurred in the summer (June through September). This pattern was true in both the baseline and the CE-s90 scenarios. However, the largest change in CSO frequency was in April, during which time the average monthly frequency increased from 0.40 to 0.59 events. October also had a large increase in CSO frequency. CSOs were infrequent in January and February, but the frequency almost doubled in these months for the CE-s90 scenario. July, August, and September had decreased CSO frequencies.

The SSO frequency decreased from 0.56 to 0.45 events per year annually. Most simulated SSO events occurred in the spring and early summer (April through July), but in this period there was little change in SSOs (there is a small increase in April). SSO frequency decreased early in the year from January to March. Late in the year the SSOs also decreased, with the exception of October, in which SSOs increased.

Figure 3-5 shows the monthly overflow volumes. The format of Figure 3-5 is similar to Figure 3-4, with two bars for CSOs and two bars for SSOs. As indicated in Figure 3-5, the CSO volume increased during all months except for a moderate decrease in August. The largest increases in CSO volume were in the spring and in October.

For the CE-s90 scenario, the monthly average SSO volumes decreased in most months so that the annual change was 25% less SSO volume as compared to the baseline scenario. April and October were the only months with a significant increase in SSO volume.

After reviewing all of the trends discussed above, there are two generalized observations:

- CSOs increased with climate change, with most of that change appearing in the spring and fall. The increase in CSOs was due to the increase in rainfall amount on the impervious area.
- SSOs decreased with climate change. The decrease in SSOs was due to the increase in temperature and evapotranspiration which dries the soil between events.

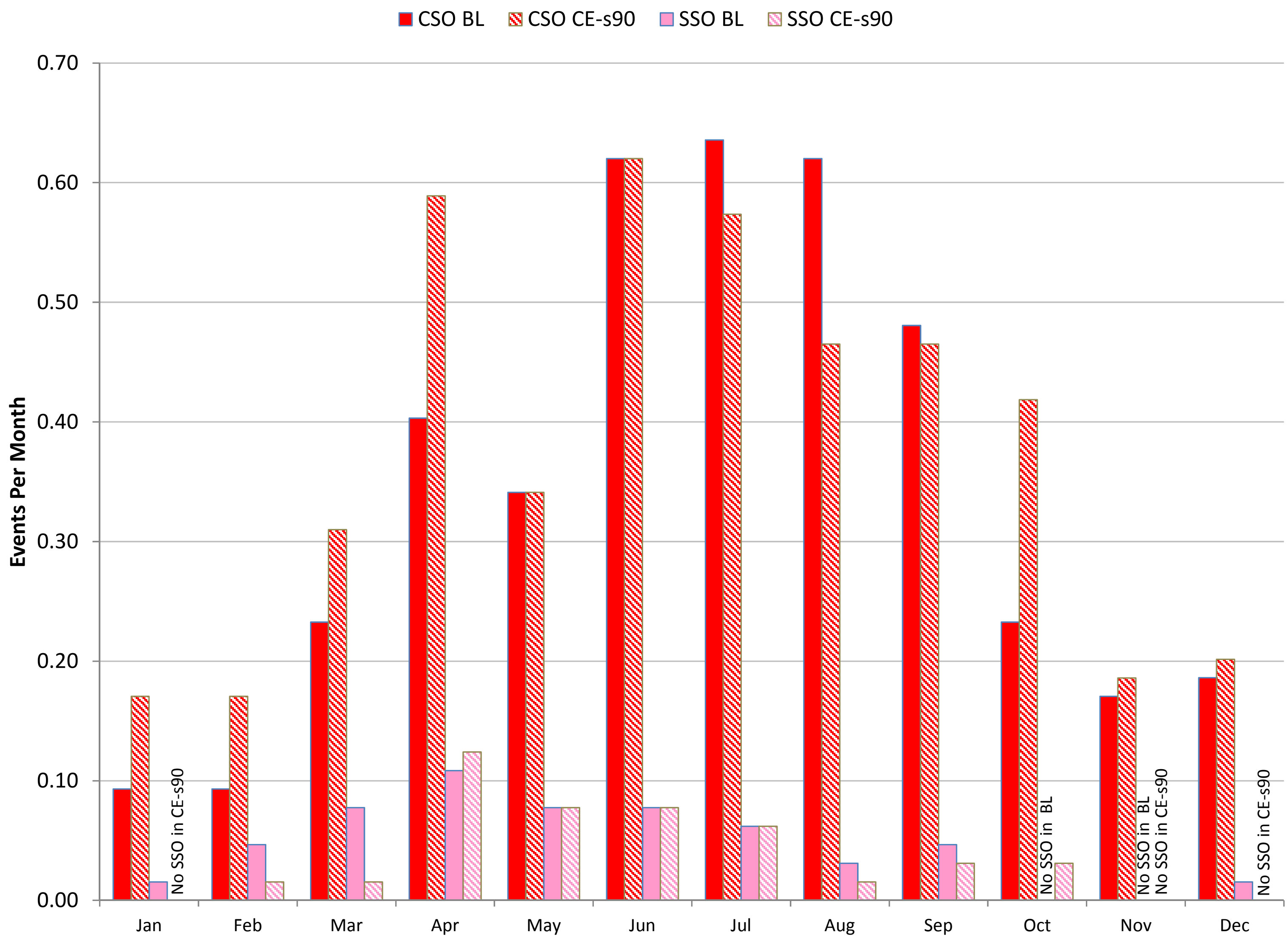

Figure 3-4. Monthly Simulated Overflow Event Frequency – Baseline and CE-s90

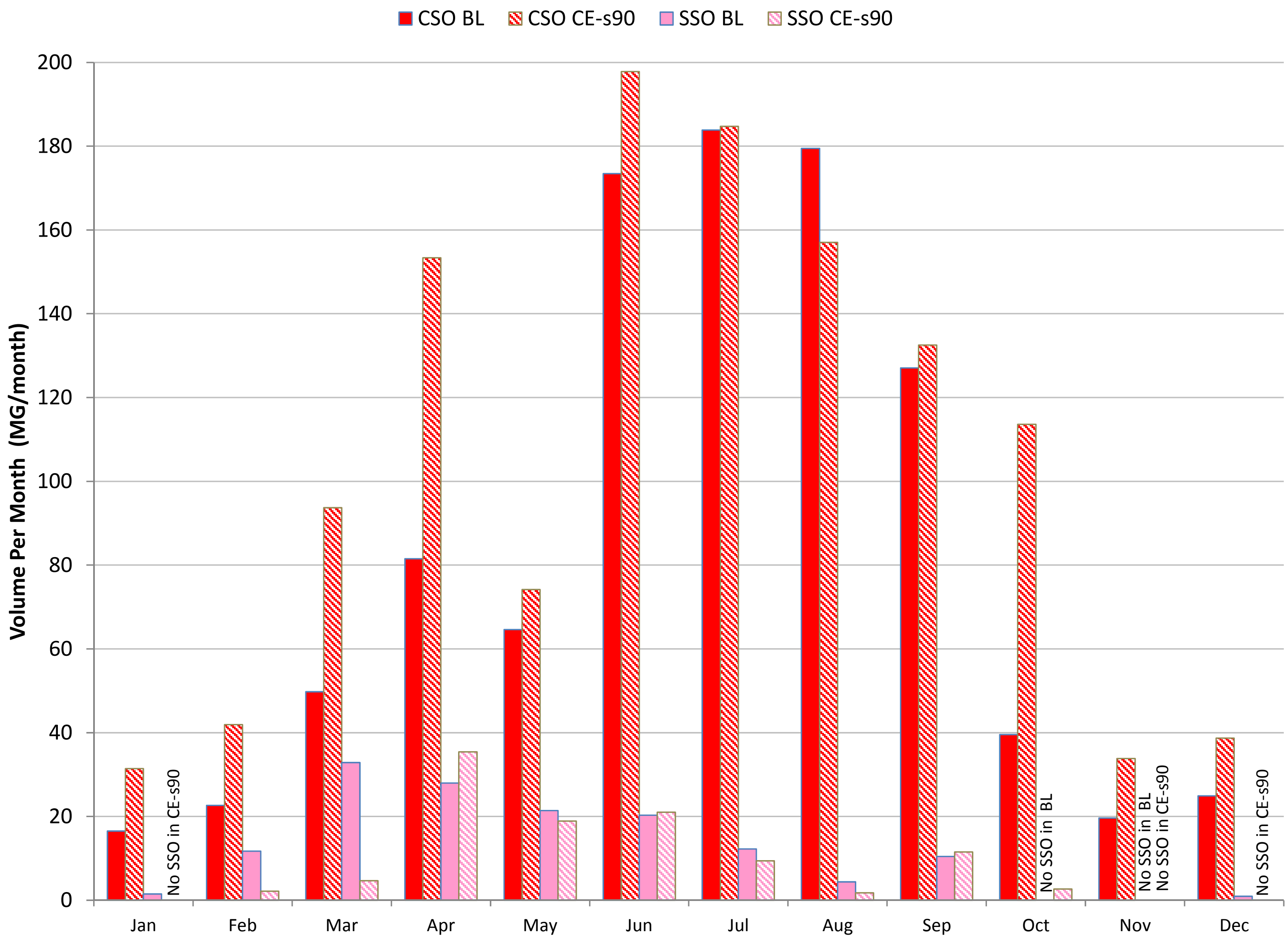

Figure 3-5. Monthly Simulated Overflow Volume – Baseline and CE-s90

3.3 Metershed Flows

The simulated metershed results provided a second approach to evaluating the climate change impacts on the District conveyance system. The 158 terminal metershed areas were used in this part of the evaluation. For each metershed, the 1-, 2-, 5-, 10-, 20-, 50- and 100-year (100%, 50%, 20%, 10%, 5%, 2%, and 1%) recurrence interval flow values were calculated from the long-term simulation results of the peak hourly flows for each climate scenario. The results were plotted as flow frequency curves. The curves were based on the 64.5-year simulation period that was used for the long-term FFS simulations. Estimated flow values in the 2- to 20-year (50% to 5%) recurrence interval range were well supported by the 64.5-year data period. Confidence in the estimates is not as strong for the larger, less frequent events, such as for the 100-year (1%) recurrence interval.

Overall, the metershed flow frequency characteristics were not dramatically changed by the various climate change scenarios. Some metersheds showed almost no change while others had a modest increase of up to 10%. The moderate climate change scenarios (CM-s10 and CE-s10) were generally very close to the baseline results; therefore these cases are not discussed further. The contrast between the baseline case and the more extreme climate scenarios (CM-s90 and CE-s90) was greater, but in the 10-year (10%) recurrence interval range, the change was typically less than 10%.

For example, Figure 3-6 shows the flow frequency curves for metershed MS0441. The 10-year (10%) recurrence interval flow for metershed MS0441 was 5.67 cubic feet per second (cfs) in the baseline case. In the CM-s90 scenario, the 10-year (10%) flow increased to 6.23 cfs (a 10% increase). For the CE-s90 scenario, the 10-year (10%) flow was 6.02 cfs (a 6% increase from baseline). The pattern in the MS0441 results was typical of many metersheds. This pattern was characterized by more change in the mid-century scenario and less change in the end-of-century scenario. The reason for this pattern has to do with the increasing evaporation in the climate change models. Precipitation and evaporation increased in both of the climate change scenarios, but the greater evaporation in the end-of-century scenario reduced the peak flows from the mid-century values.

In most metersheds the 10-year (10%) flows were greatest for the CM-s90 scenario (with changes up 10% from the baseline scenario) and lowest for the CE-s90 scenario (with changes up to 6% greater than the baseline scenario). However, in some cases the 10-year (10%) flow values in the climate change scenarios were essentially unchanged from baseline scenario. In other cases the flow values for the climate change scenarios were less than the baseline scenario.

Figure 3-7 provides the flow frequency curves for MS0213. In this metershed the flows from the climate scenarios were less than or equal to those of the baseline scenario.

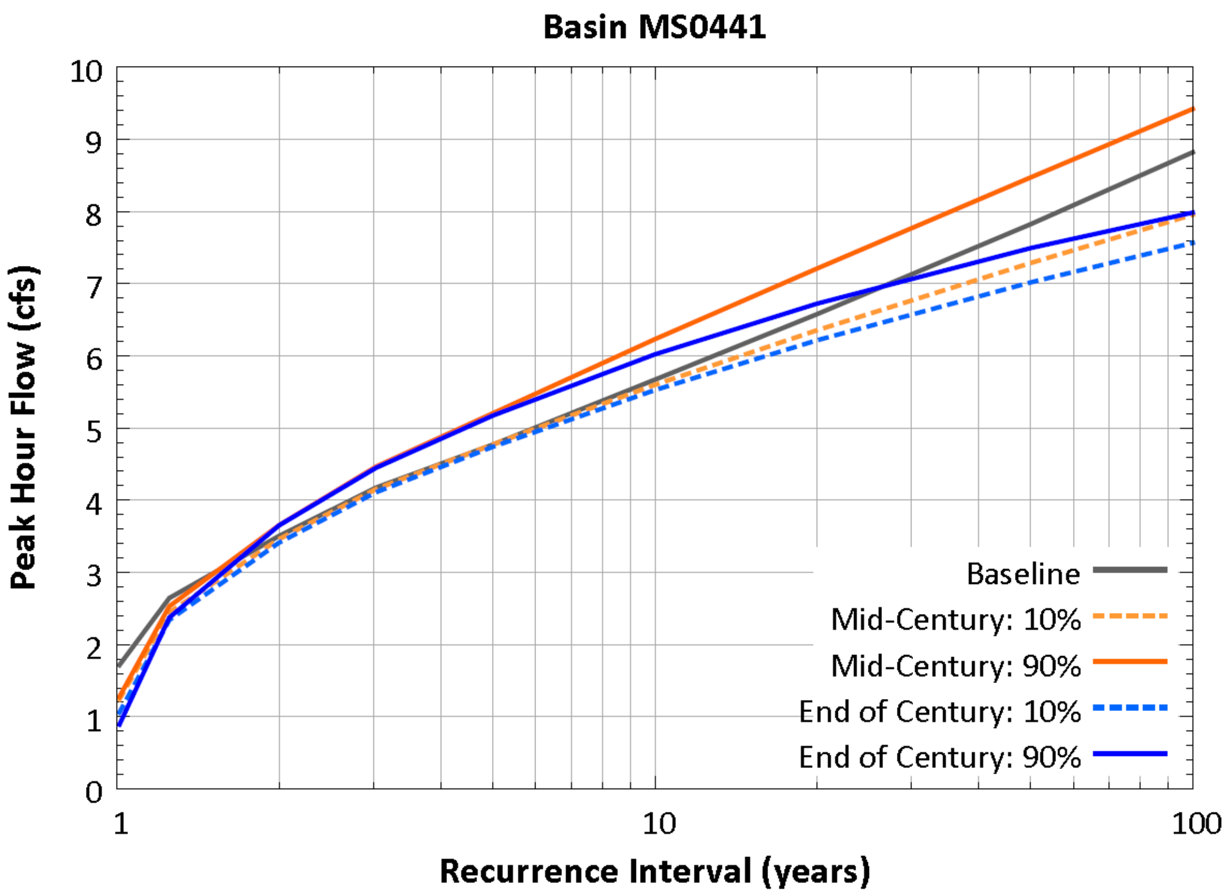

Figure 3-6. Metershed MS0411 Flow Frequency Curves

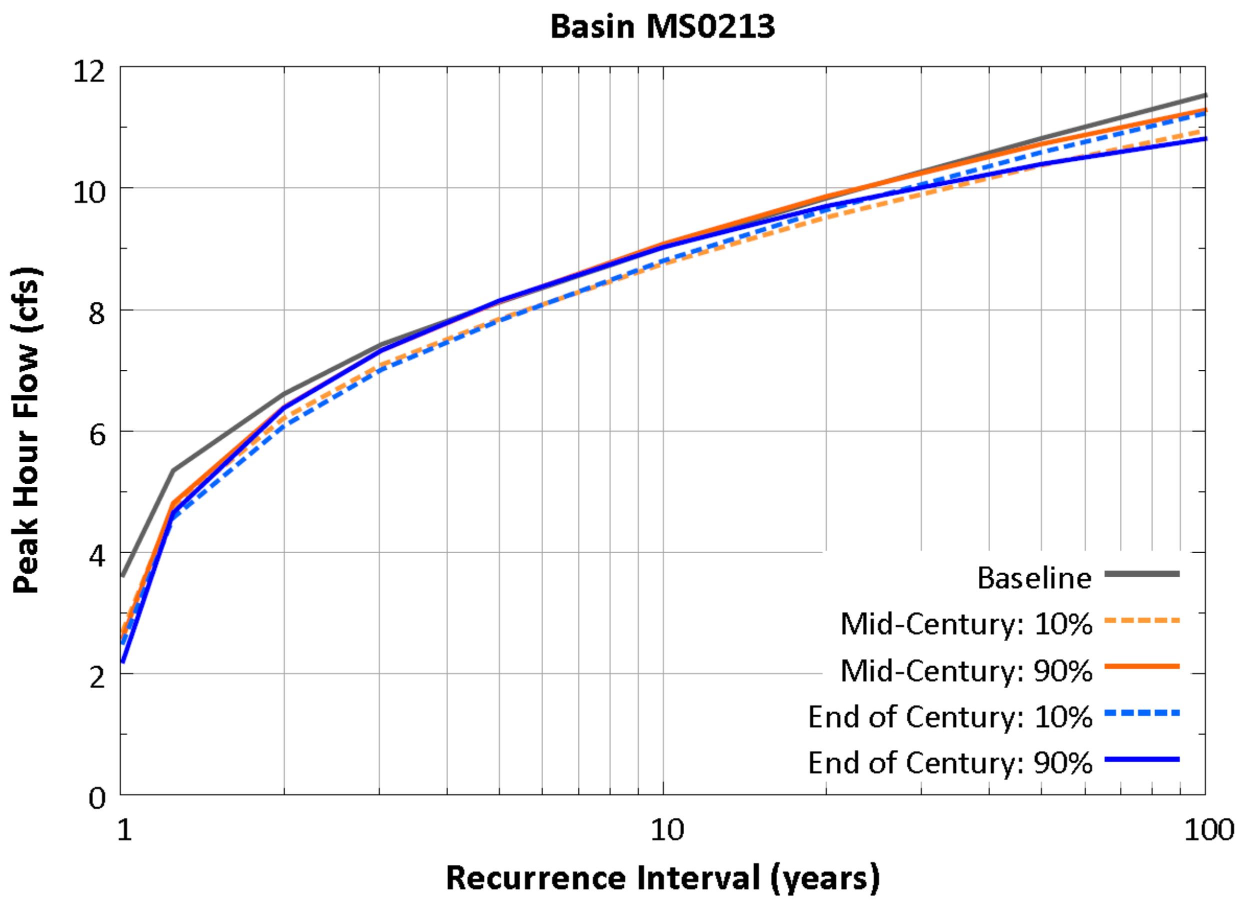

Figure 3-7. Metershed MS0213 Flow Frequency Curves

Figure 3-8 shows a plot of the change in the metershed 10-year(10%) peak hourly flows. The plot shows the change in the CM-s90 and CE-s90 values relative to the baseline 10-year (10%) flow values. The x-axis is the metershed wetness, expressed as the flow per unit area (units of gallons per acre per day, gpad). The y-axis is the percent change from the baseline values. While there is scatter in the results, the maximum change is generally 10% or less for the CM-s90 scenario, and generally 6% or less for the CE-s90 scenario. The scatter in the results for the wetter metersheds was less than the drier metersheds. A few metersheds had a reduction in the 10-year (10%) flow values (negative change in the graph).

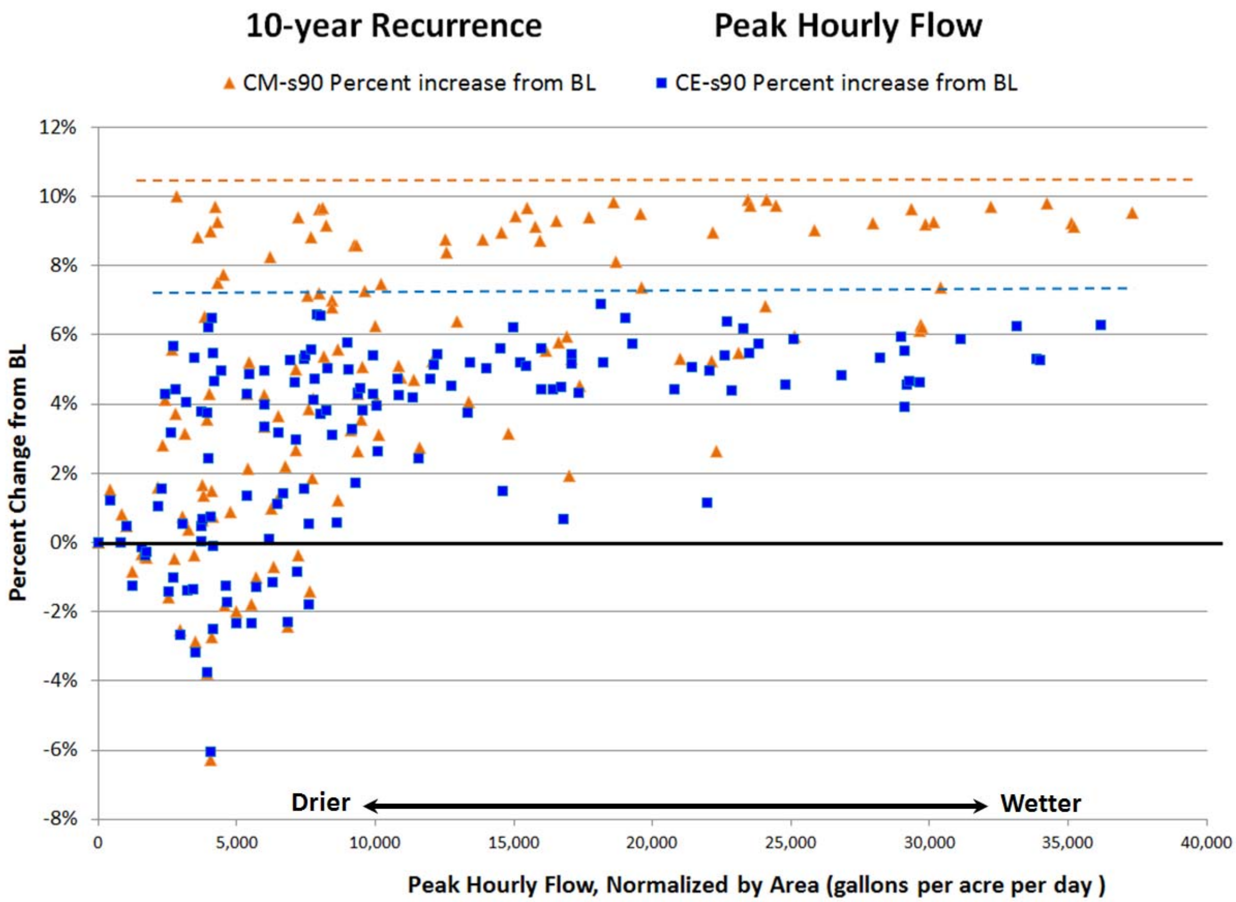

Figure 3-8. Metershed 10-year Peak Hourly Flow: Percent Change from Baseline

A few sewersheds in the combined sewer service area (CSSA) were also evaluated along with the separate metersheds discussed above. With the exception of a small area, there are no flow meters in the CSSA. The flows from the CSSA are only monitored with the influent flow to the Jones Island WRF. As a result, the CSSA was not subdivided into metershed basins for the climate change evaluation. Nevertheless, the evaluation of climate change was extended to the CSSA by evaluating the flow frequency characteristics of four sewersheds.

Three of the sewersheds were relatively small in size, ranging from 30- to 40-acres, and the fourth sewershed was larger (339 acres). The sewersheds were selected to represent a range of impervious values; the impervious values ranged from 30 percent (low) to 98 percent (high).

The relative change in flows for these CSSA sewersheds was similar to the relative change observed in the separate area metersheds. Figure 3-9 shows the flow frequency curves for sewershed CS4188#1, the largest evaluated sewershed in the CSSA. The flow frequency curves had an upward bend for the longer recurrence intervals. This implies a greater impact by climate change on the largest wet weather events. The natural uncertainty with predicting the 100-year recurrence interval flow values should be recognized when drawing inferences from the extreme end of the curves.

Figure 3-10 shows the curves for sewershed CS7215#2, which is a 40-acre sewershed with an impervious value of 98 percent. The results for the other CSSA sewershed are very similar to these, with the mid-century 10-year flows at 12% to 13% greater than the baseline case. The end-of-century flows are 8% to 10% greater than the baseline scenario.

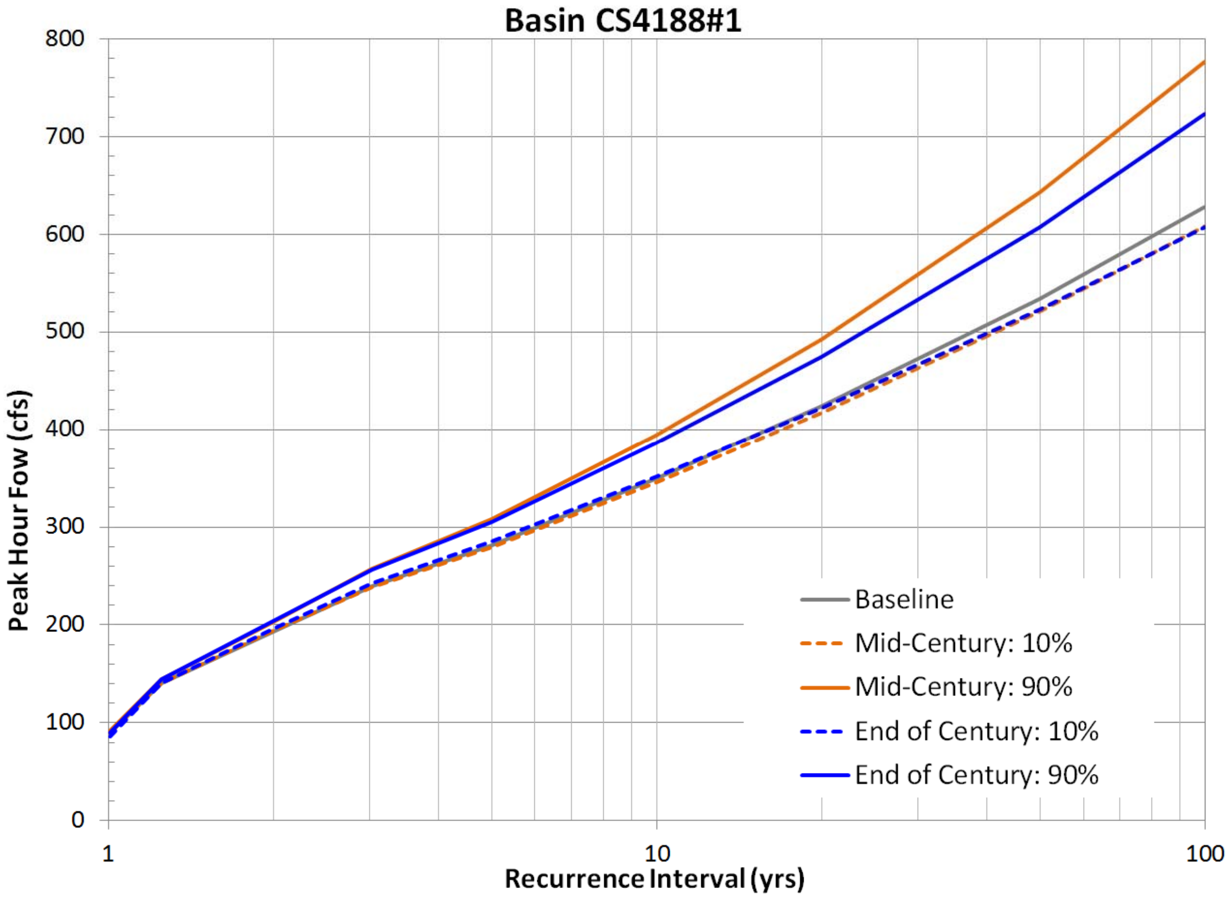

Figure 3-9. Sewershed CS4188#1 Flow Frequency Curves

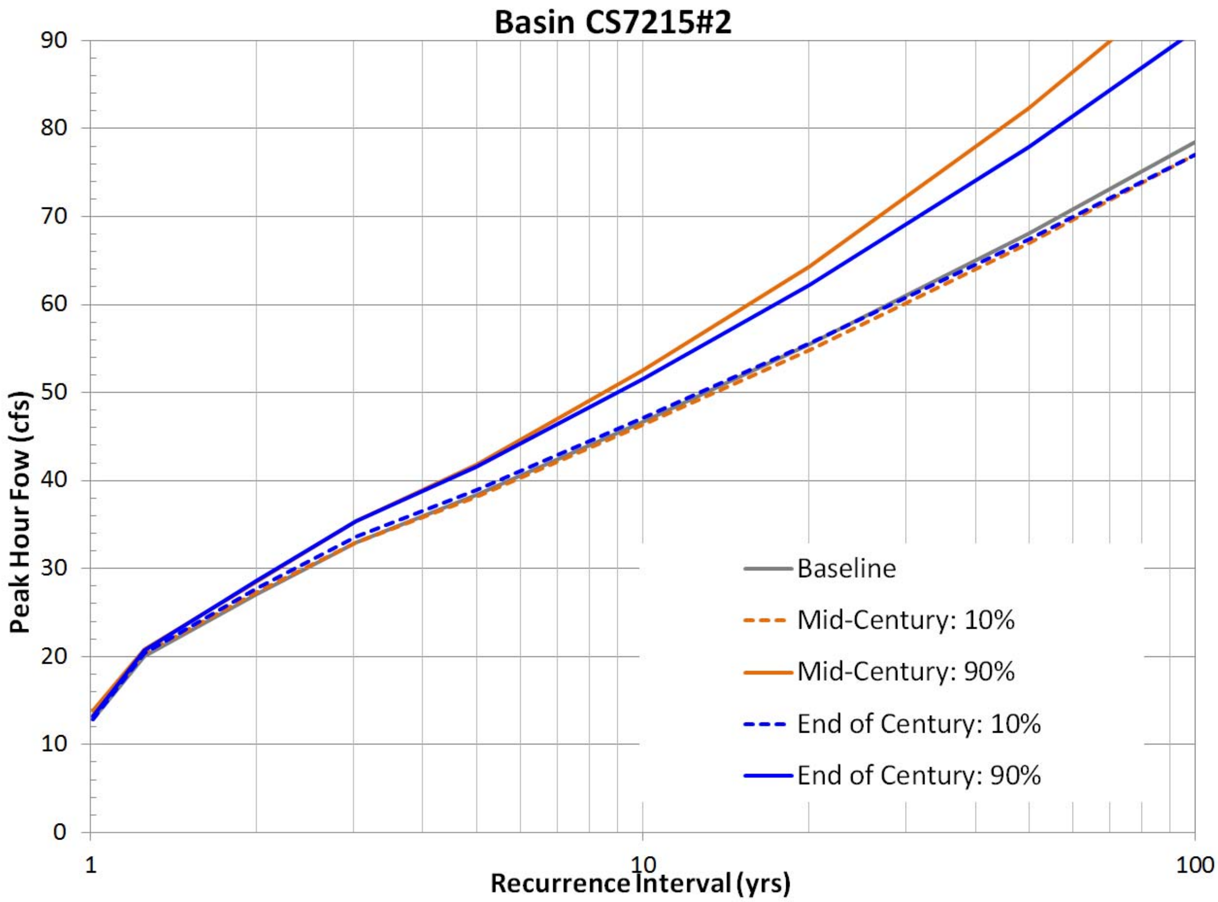

Figure 3-10. Sewershed CS7215#2 Flow Frequency Curves

Appendix D contains a graph of the flow frequency curves for each terminal metershed in the District service area. Each graph has five curves, one for each scenario.

Appendix D also contains a table of metershed flow frequency values. The table lists the 1-, 2-, 5-, 10-, 20-, 50- and 100-year recurrence interval flow values.

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Section 4: Watercourse Impacts

The objective of the watercourse analysis was to estimate the impact of climate change on base flows and peak flows for two jurisdictional watercourses within the District service area. The Menomonee and Kinnickinnic rivers were selected for evaluation because most of their watersheds are within the District service area and flow models for these rivers were readily available. The watercourse flow HSPF models of the Menomonee River and the Kinnickinnic River were obtained from SEWRPC and simulated with the rainfall and evaporation data for the 90% mid-century and 90% end-of-century scenarios.

Similar to the work that was conducted for the conveyance system modeling, the impact of climate change was analyzed to determine the possible impacts on watercourses. Peak, average, and low flows were evaluated for the downstream-most reach of the Kinnickinnic and Menomonee rivers for the baseline, mid-century 90%, and end-of-century 90% scenarios. Schematics of the river reaches are shown in Figures 4-1 and 4-2.

4.1 Approach

Hydrologic models had been previously constructed for both the Kinnickinnic and Menomonee rivers. There are two sets of each model and both were obtained from SEWRPC:

1. The first set of models was developed as part of the floodplain mapping program for the Milwaukee County Automated Mapping and Land Information System (MCAMLIS) Steering Committee and the District. These were used for this analysis because they are the most recent and they reflect the planned year 2020 land use and existing channel conditions.
2. The second set was developed as part of the joint District/SEWRPC/Wisconsin Department of Natural Resources (WDNR) water quality planning project known as the Water Quality Initiative (WQI).

4.1.1 Point Sources

The second set of models includes point sources that represent CSOs, SSOs and industrial cooling water discharges. The industrial cooling water discharge point sources were not included in the modeling for the floodplain mapping (set 1) because the magnitude of the combined point source flows was not significant when compared to the larger flood event flows. It is assumed that the volume of cooling water discharges will not change substantially over time.

The objective of the climate change analysis was to compare the relative change between the baseline, mid-century, and end-of-century scenarios as opposed to the overall flow. This comparison was made for a range of flows (peak, average and low flows). In an attempt to isolate the change that could occur based on natural processes, the point sources were also left out of this analysis. For example, even the industrial cooling water discharge combined flow was significant when compared to the lowest flows. The lowest simulated hourly flow for the Kinnickinnic River is less than 0.1 cfs whereas the sum of the peak industrial cooling water discharges ranges from 1.3 to 6.5 cfs. All but two of the cooling water discharges to the Kinnickinnic River are constant, based on the data provided by SEWRPC. The data for the other two discharges show some slight variability from month

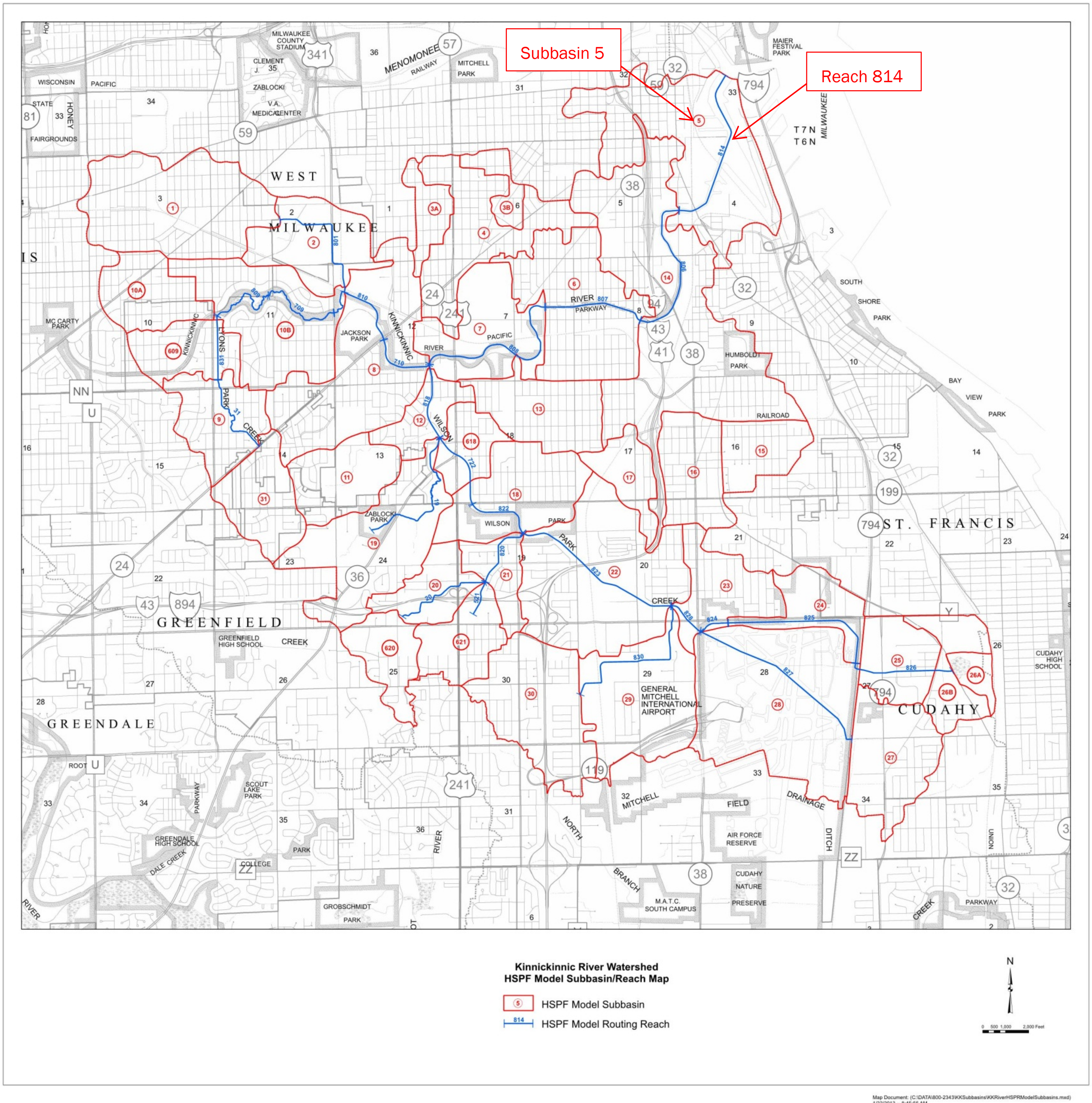

Figure 4-1. Kinnickinnic River Model Reaches

Source: SEWPRC

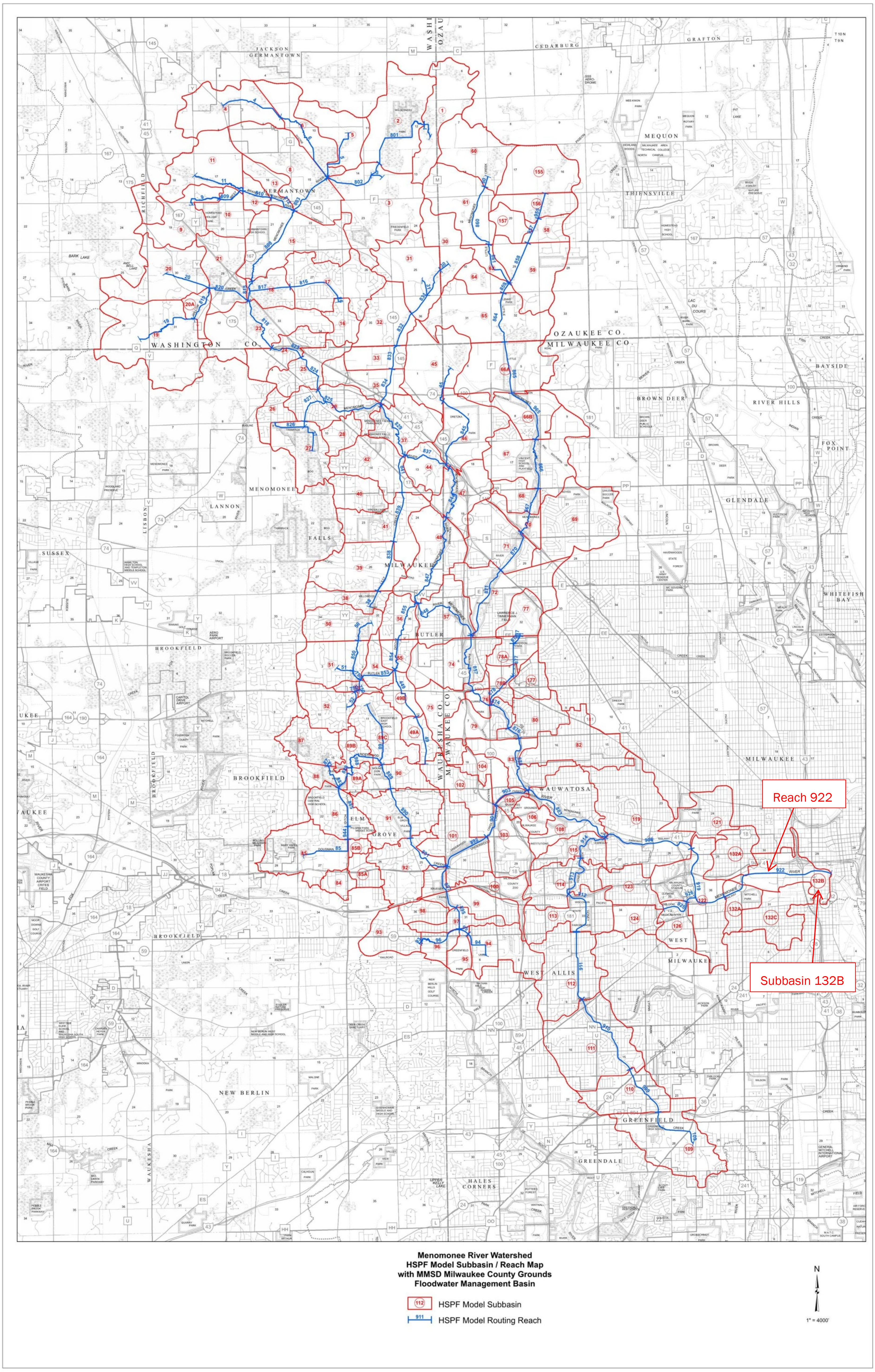

Figure 4-2. Menomonee River Model Reaches

Source: SEWRPC

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to month. The nature of that variability is unknown. The lowest simulated hourly flow for the Menomonee River is also less than 0.1 cfs and the sum of the peak industrial cooling water discharges is 4.0 cfs. All of the cooling water discharges to the Menomonee River are constant, based on the data provided by SEWRPC. By including these point sources, the effects of climate change could be masked and thus the true impact may not be identified.

4.1.2 Modeling

Each river model was simulated with the same climate scenario files that were used for the conveyance system impact evaluation. Baseline, mid-century 90% and end-of-century 90% scenarios were run for both the Kinnickinnic and Menomonee rivers. All model runs had a simulation start date of January 1, 1940 and a simulation end date of June 30, 2004, with a precipitation time step of one hour and a simulation time step of one hour. A precipitation and simulation time step of one hour was used to allow for consistency between scenarios as the end-of-century precipitation data was only available with a one-hour time step.

Model results were analyzed for two locations in each river: the downstream-most reach and the next most downstream reach. The two most downstream reaches for each river were analyzed to assess whether the relative differences in results for climate change scenarios were dependent on reach location. For the Kinnickinnic River, the reaches identified as “Mouth” and “814” were analyzed. The flow associated with the Reach Mouth in the Kinnickinnic River model represents the total basin flow and is the sum of the routed flow through Reach 814 and the runoff from Subbasin 5, as shown in Figure 4-1. For the Menomonee River, the reaches identified as “922A” and “922B” were analyzed. Reach 922B represents the total flow from the basin and includes the sum of the routed flow in Reach 922 and the runoff from Subbasin 132B, as shown in Figure 4-2. These reach names are the same names included in the HSPF models and also the SEWRPC Floodplain Mapping Program results tables. The results of the analyses demonstrated that the relative changes in flows between scenarios were roughly the same for the two reaches in each river. Therefore, only the results for the downstream-most reaches are presented in this section.

Several statistics were computed for each river reach. They included:

- Peak Flow Frequency Analysis
- Average Daily Flow
- Bankfull Flow
- Low Flow/Duration Statistics

For the peak flow frequency analysis, hourly annual peak flows that were calculated on a water year basis (October to October) were selected from the results of the long-term simulation. The water year basis was used to be consistent with SEWRPC’s previous analyses and typical hydrologic practice. Each set of results for each river reach was then fit to a Log Pearson Type III distribution.

4.2 Peak Flows

Tables 4-1 and 4-2 summarize the results of the flow frequency analyses for the Kinnickinnic River and Menomonee River, respectively. The percentages shown under the flow values for the mid-century and end-of-century indicate the percent difference from the baseline scenario. A positive value indicates an increase in flow.

Graphical results of the peak flow frequency analysis for the downstream reach of the Kinnickinnic River and Menomonee River can be found in Figures 4-3 and 4-4, respectively.

	Table 4-1. Kinnickinnic River Peak Flow Frequency Analysis Results								
HSPF Reach No.	Description	Scenarios		Annual Peak Flows (cfs)					
			1-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Mouth	Mouth - Union Pacific Railroad	Baseline	1,500	4,300	6,700	8,600	11,300	13,500	16,000
		CM-s90	1,590	4,400	7,000	9,100	12,400	15,300	18,500
			6%	2%	4%	6%	10%	13%	16%
		CE-s90	1,620	4,500	7,100	9,200	12,300	15,000	18,000
			8%	5%	7%	8%	9%	11%	12%

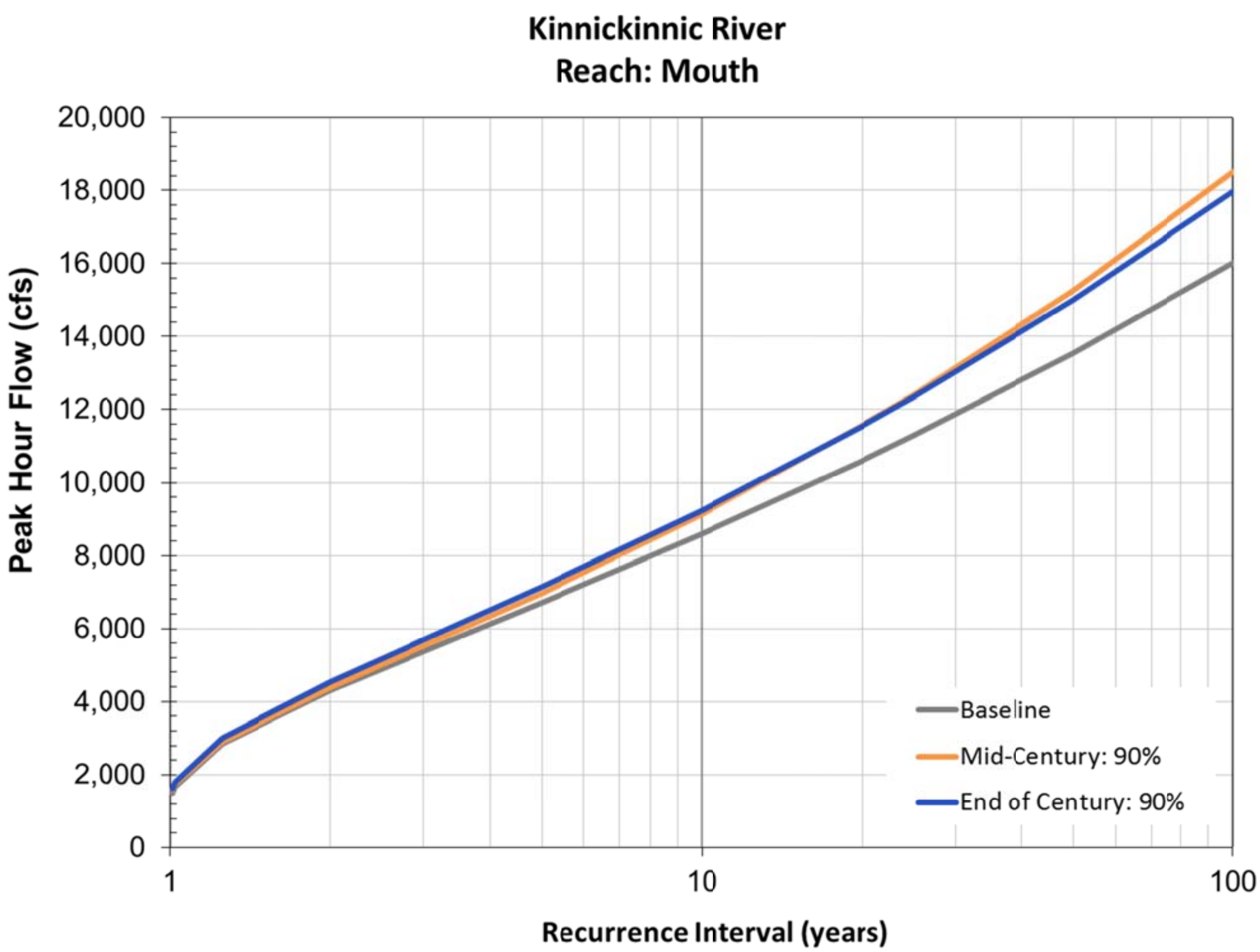

Figure 4-3. Kinnickinnic River Peak Flow Frequency Analysis, Reach: Mouth

Table 4-2. Menomonee River Peak Flow Frequency Analysis Results									
HSPF Reach No.	Description	Scenarios	Annual Peak Flows (cfs)						
			1-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
922B	Mouth - Menomonee Canal	Baseline	1,700	5,500	8,800	11,300	15,000	18,000	21,400
		CM-s90	1,720	5,700	9,400	12,400	16,900	20,700	24,900
			1%	5%	8%	10%	12%	14%	16%
		CE-s90	1,660	6,000	9,800	12,800	17,000	20,600	24,400
			-2%	9%	12%	13%	14%	14%	14%

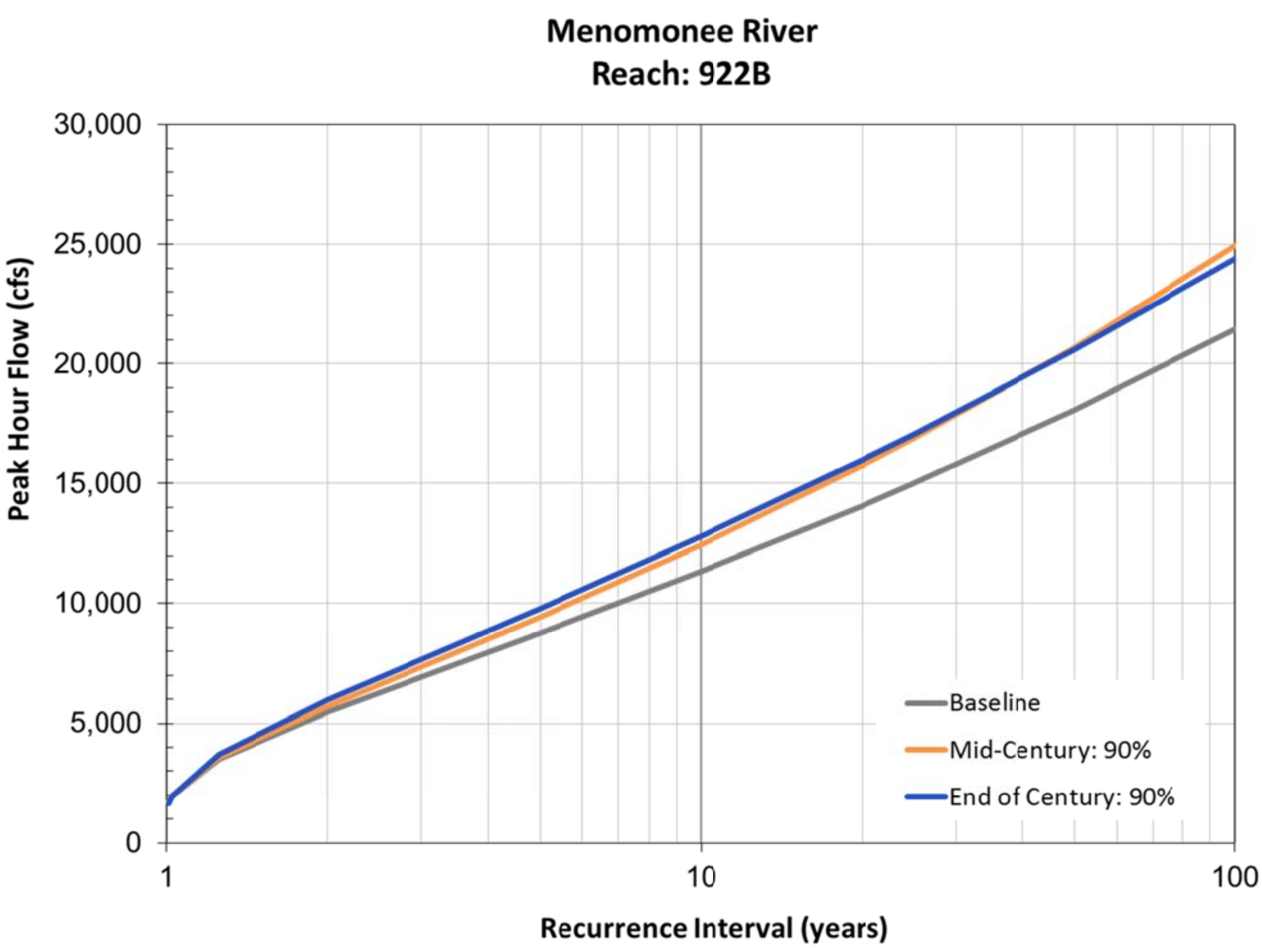

Figure 4-4. Menomonee River Peak Flow Frequency Analysis, Reach: 922B

4.3 Bankfull Flow

Bankfull flow represents the channel forming flow or amount of flow that fills the channel and begins to spill onto the floodplain. The bankfull stage may be difficult to identify in entrenched or degraded streams. Bankfull flow in urban areas generally ranges between the 1-year and 2-year recurrence interval, with the average of 1.5-year generally used as the starting point for stream restoration design. For this analysis, the 1-year and 2-year peak flows derived from the Peak Flow Frequency Analysis were averaged. Tables 4-3 and 4-4 show the bankfull flows for each scenario for the Kinnickinnic and Menomonee rivers, and the relative changes from the baselines. A positive value indicates an increase in flow.

Table 4-3. Kinnickinnic River Bankfull Flow Results

HSPF Reach No.	Description	Scenarios	Average Daily Flow (cfs)
Mouth	Mouth - Union Pacific Railroad	Baseline	2,900
		CM-s90	3,000
			3%
		CE-s90	3,100
			6%

Table 4-4. Menomonee River Bankfull Flow Results

HSPF Reach No.	Description	Scenarios	Average Daily Flow (cfs)
Mouth	Mouth - Menomonee Canal	Baseline	3,600
		CM-s90	3,700
			4%
		CE-s90	3,800
			7%

4.4 Average Daily Flows

The average flow over the period of record was calculated. Tables 4-5 and 4-6 show the average daily flows and the relative changes from the baselines for each scenario for the Kinnickinnic and Menomonee rivers. A negative value indicates a decrease in flow.

Table 4-5. Kinnickinnic River Average Daily Flow Results			
HSPF Reach No.	Description	Scenarios	Average Daily Flow (cfs)
Mouth	Mouth - Union Pacific Railroad	Baseline	33.5
		CM-s90	30.2
			-10%
		CE-s90	29.1
			-13%

Table 4-6. Menomonee River Average Daily Flow Results			
HSPF Reach No.	Description	Scenarios	Average Daily Flow (cfs)
Mouth	Mouth - Menomonee Canal	Baseline	139.1
		CM-s90	120.0
			-14%
		CE-s90	113.6
			-18%

4.5 Low Flows

An evaluation of the low flows (base flows) in the Kinnickinnic and Menomonee rivers was also completed. The low flow statistics were calculated using Design Flow Analysis (DFLOW) 3.1. DFLOW was developed by the U.S. Environmental Protection Agency (EPA) to estimate design-stream flows for low flow analyses and water quality standards.

The average daily flows for each stream reach were entered into DFLOW. The low flow design methods were 7Q10, 1B3, and 4B3, each of which is described below.

7Q10 Flow

The 7Q10 is a hydrologically-based design flow. It represents the lowest seven-day average flow that occurs with a frequency of once every ten years. The hydrologically-based design flow method was initially developed by the U.S. Geological Survey to answer questions relating to water supply. It is now also used in the determination of aquatic life criteria.

1B3 Flow

The 1B3 is a biologically-based design flow. It represents a one-day average flow that occurs with a frequency of once every three years. The biologically-based design flow method was developed by the U.S. EPA Office of Research and Development and includes all low flow events within a period of record, even if several occur in one year. The biologically-based design flow method is intended to represent the actual frequency of biological exposure.

4B3 Flow

The 4B3 is also a biologically-based design flow. It represents the four-day average flow event that occurs with a frequency of once every three years.

The low flow/duration statistics are summarized in Tables 4-7 and 4-8. The percentages shown under the flow values for the mid-century and end-of-century indicate the percent difference from the baseline scenario. A negative value indicates a decrease in flow.

Table 4-7. Kinnickinnic River Low Flow Analysis Results

HSPF Reach No.	Description	Scenarios	Low Flow (cfs)		
			7Q10	1B3	4B3
Mouth	Mouth - Union Pacific Railroad	Baseline	0.57	0.51	0.56
		CM-s90	0.29	0.24	0.23
			-49%	-53%	-59%
		CE-s90	0.21	0.17	0.16
			-63%	-67%	-71%

Table 4-8. Menomonee River Low Flow Analysis Results

HSPF Reach No.	Description	Scenarios	Low Flow (cfs)		
			7Q10	1B3	4B3
922B	Mouth - Menomonee Canal	Baseline	1.58	1.42	1.68
		CM-s90	0.74	0.62	0.65
			-53%	-56%	-61%
		CE-s90	0.52	0.46	0.45
			-67%	-68%	-73%

Flow duration curves were developed using the average daily flow from the simulations. The full flow duration curves for the most downstream reaches of the Kinnickinnic River and Menomonee River are shown in Figure 4-5 and Figure 4-6, respectively. Figures 4-7 and 4-8 include flow duration curves with a modified y-axis scale; the scale was capped at the just above the average daily flow from the baseline scenario. These modified curves help identify the resulting differences between the scenarios for the lowest flows.

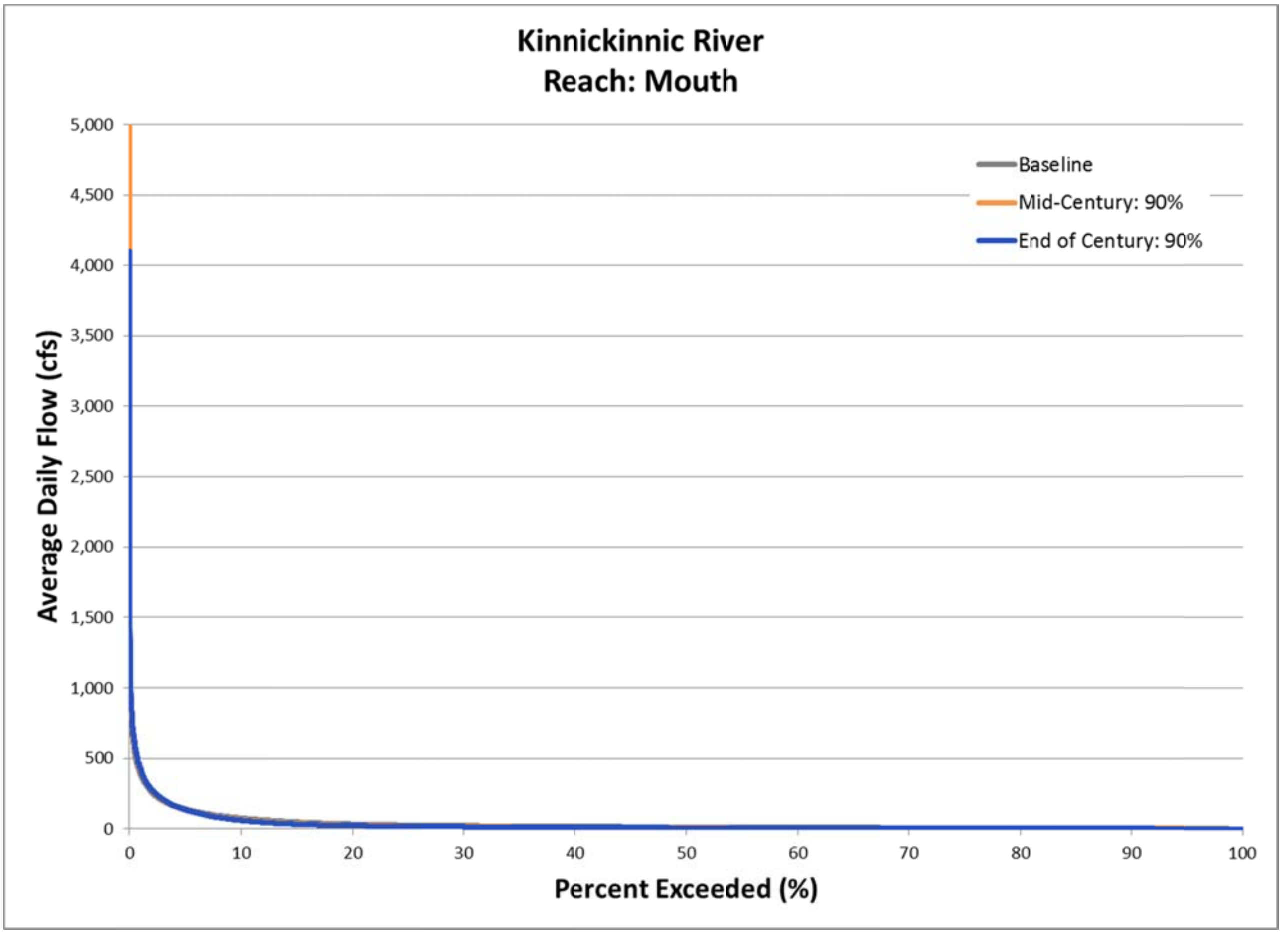

Figure 4-5. Kinnickinnic River Flow Duration Curves, Reach: Mouth

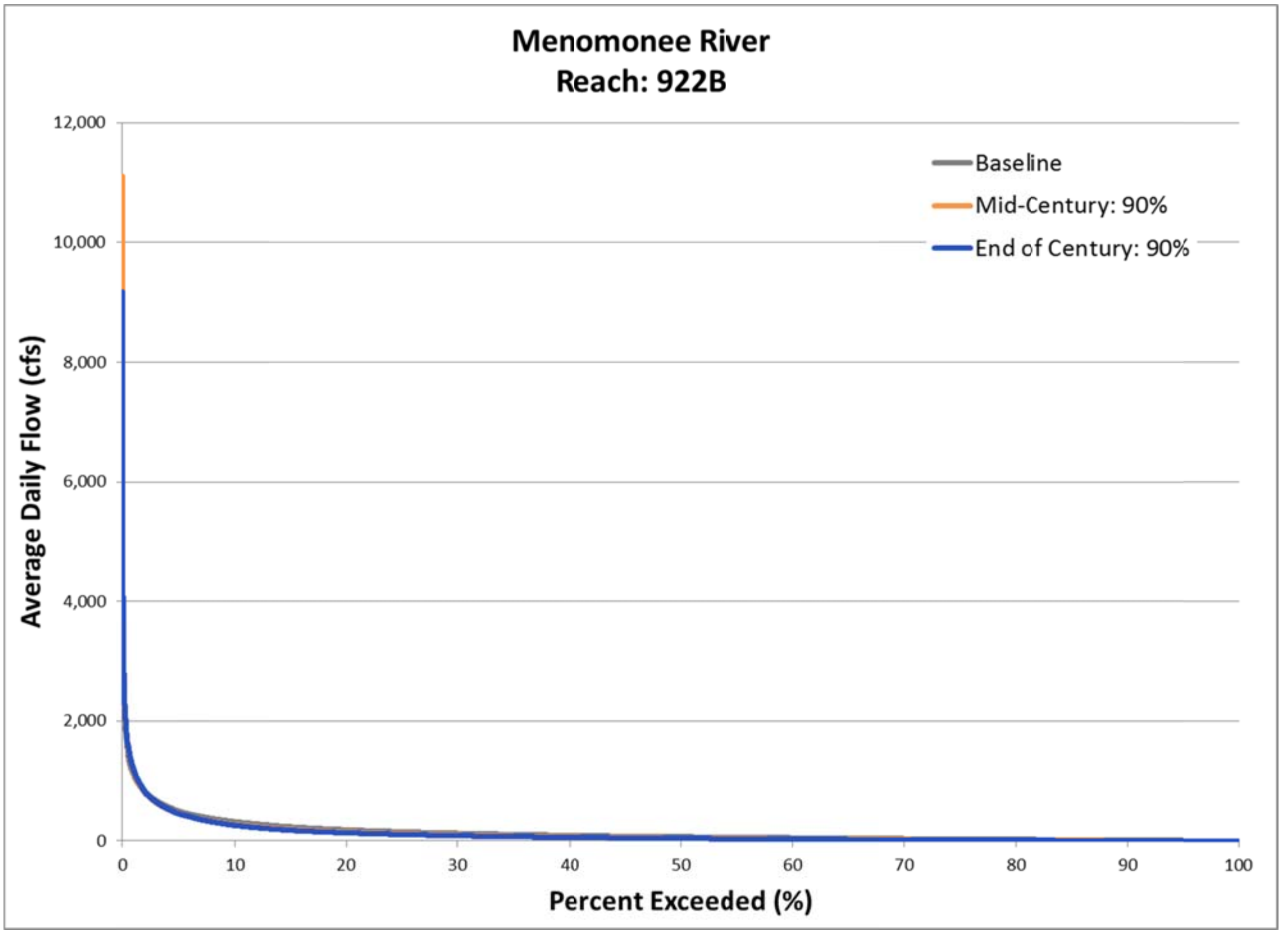

Figure 4-6. Menomonee River Flow Duration Curves, Reach: 922B

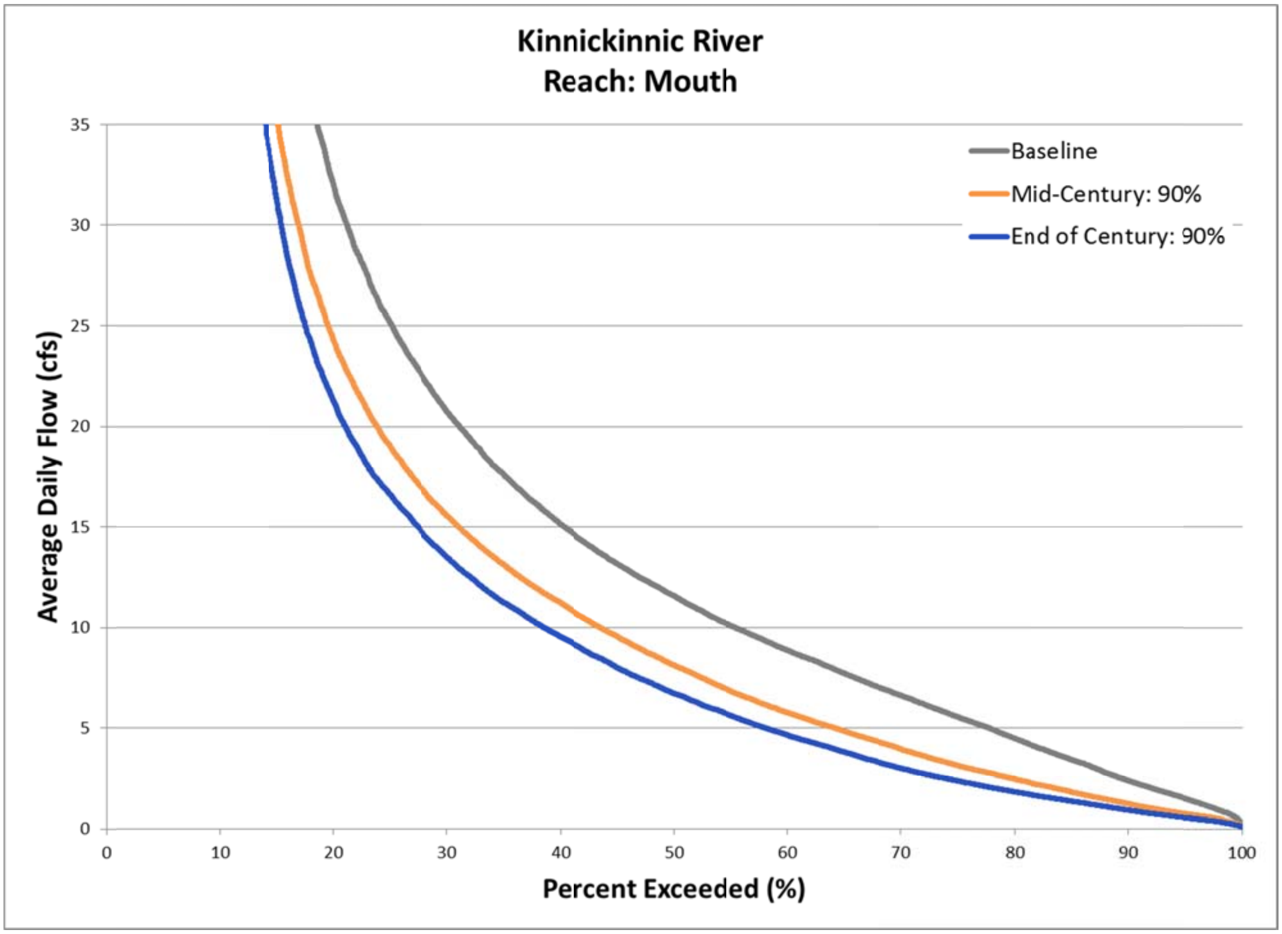

Figure 4-7. Kinnickinnic River Flow Duration Curves, Modified y-axis scale, Reach: Mouth

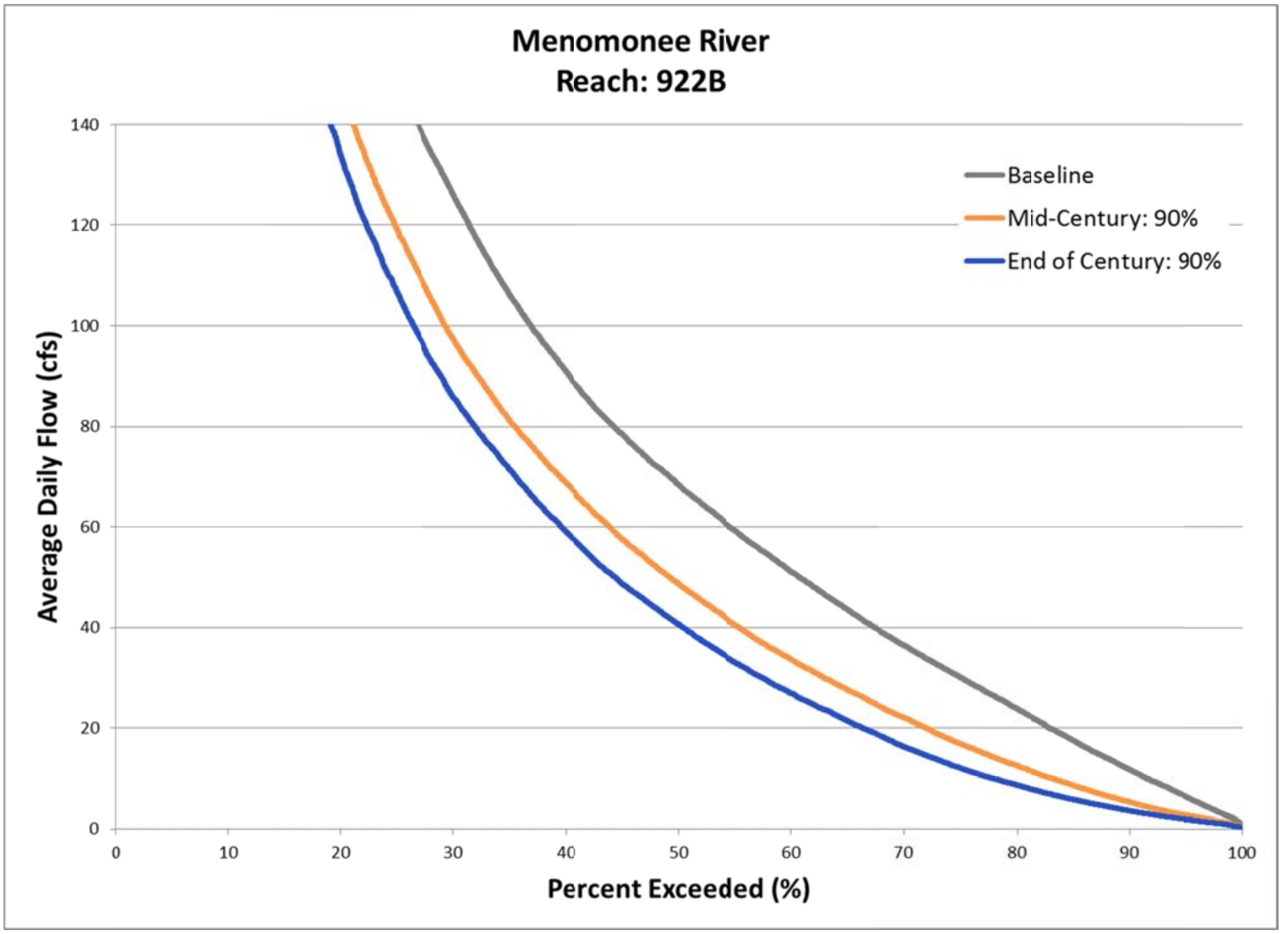

Figure 4-8. Menomonee River Flow Duration Curves, Modified y-axis, Reach: 922B

4.6 Discussion

The peak flow frequency analysis indicates that peak flows increase for both the mid-century and end-of-century scenarios for all recurrence intervals. Simulations of the peak flows for the Kinnickinnic River showed an increase between 2% and 16%, with the larger increases found in the events that occur less frequently. Peak flows for the Menomonee River increased between 5% and 16%, also with the larger increases found in the events occurring less frequently. Flows for the smaller recurrence intervals (2- through 10-year) generally increased more in the end-of-century scenario, whereas flows for the larger recurrence intervals (25- through 100-year) generally increased more in the mid-century scenario. The overall increase in flows is a reflection of the larger, more intense rainfall events that are predicted in the mid-century and end-of-century scenarios. For the larger recurrence intervals, the larger increase in the mid-century flows as compared to end-of-century flows is a result of the increased PET that is associated with the end-of-century climate scenario. These peak flow increases will substantially increase the future risk of flood damages and reduce the level of service of the major District investments in flood management.

Simulations of bankfull flows showed an increase of between 3% and 7% for the scenarios evaluated. Although the results indicate an increase in bankfull flow, stream degradation will likely not be significant.

The average daily flows decreased by a range of 10% to 18% for the evaluated scenarios. This is a significant decrease in average daily flow and will likely impact aquatic habitat, water quality, and aquatic species viability.

All of the low flow duration analyses indicated that low flows decrease for both the mid-century and end-of-century scenarios. In addition, all indicated that the end-of-century low flows decrease more than the mid-century low flows. Although the percent decrease is significant (up to 73%), the absolute incremental decrease is small. These changes are minor relative to industrial cooling water point source contributions to the river base flows. Although these changes in low flows could have some impact on the temperature of the low flows in the river due to the somewhat decreased dilution of the cooling water discharges, it is difficult to speculate on the probability of this because the calculated changes in low flows may be within the accuracy of the model calibrations for such low flow values. Therefore, the impacts of decreased low flows are expected to be the same as the qualitative impacts identified above for changes in average daily flows.

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Section 5:

Green Infrastructure Impacts: Rainfall Distribution Changes

The objective of this analysis was to evaluate the effect of climate change on the frequency and depth of precipitation events. The analysis specifically addressed how climate change impacts smaller precipitation events because these events are directly related to the use of green infrastructure technologies.

The frequency and depth of precipitation events was evaluated for three climate scenarios:

- Baseline: Existing Climate
- Mid-Century 90% climate scenario (CM-s90)
- End-of-Century 90% climate scenario (CE-s90)

The data series were evaluated for the 64.5-year period from January 1940 through June 2004. This is the same period of evaluation used for the other components of the Climate Change Vulnerability Analysis.

5.1 Approach

Precipitation events were identified and separated out of the continuous data record by identifying periods of 24 hours or longer that did not have any precipitation.

After identifying the events, the average annual frequency of events was calculated as the total number of precipitation events divided by the 64.5 years in the data record. The average annual precipitation depth was calculated as the sum of precipitation depths divided by the 64.5-year period.

The statistics for precipitation depth and event frequency were also computed for each calendar quarter of the year:

First quarter, Q1:	January to March
Second quarter, Q2:	April to June
Third quarter, Q3:	July to September
Fourth quarter, Q4:	October to December

In this discussion the terms “rain” and “precipitation” are used interchangeably. The data used for the analysis is the water equivalent of the precipitation; the form of the precipitation (as rain, snow, hail, etc.) is not defined. In the text, and in the figure and table labels, the terms “rain” or “rainfall” are used when a concise term helps the flow of the discussion, instead of the more general term “precipitation.”

In addition to evaluating the precipitation data on annual and quarterly bases, the precipitation events were further subdivided into large and small events. Small events were defined to be those with a rainfall depth less than 0.5 inch. This cutoff value was used to divide events into large and small categories because it is assumed that green infrastructure technologies could be used to manage events with less than 0.5 inch of rainfall.

For the purpose of this evaluation, it is assumed that in large events the first 0.5 inch of rainfall is controlled by green infrastructure and the excess rainfall after the first 0.5 inch is managed by the stormwater conveyance system (whether it is a combined sewer or a storm sewer, swale or ditch in the separated area).

The large and small event results were tabulated for annual average values and quarterly average values for each climate scenario.

5.2 Rainfall Distributions

Table 5-1 summarizes the frequency of rainfall events. In the baseline case, there was an average of approximately 77 rainfall events per year. This corresponds to a rainfall event every four to five days, on average. Many of these events were small. The frequency of events less than 0.5 inch was approximately 57 events per year and the frequency of larger events was approximately 20 events per year.

Table 5-1. Precipitation Event Frequency

Scenario	Average Number of Precipitation Events (events/year)														
	All Events					Small Events (Less than 0.5 inch)					Large Events (Greater than or equal to 0.5 inch)				
	Q1	Q2	Q3	Q4	Annual	Q1	Q2	Q3	Q4	Annual	Q1	Q2	Q3	Q4	Annual
Baseline	19.2	20.6	18.6	18.3	76.8	15.7	14.0	12.5	14.1	56.4	3.5	6.6	6.1	4.3	20.4
CM-s90	19.8	19.2	17.4	17.5	73.8	15.6	12.9	11.7	12.9	53.1	4.2	6.2	5.7	4.5	20.7
CE-s90	17.8	19.0	16.5	16.2	69.6	13.6	12.9	11.2	11.5	49.2	4.2	6.1	5.3	4.7	20.4

Table 5-2. Average Precipitation Depth

Scenario	Average Annual and Quarterly Precipitation Depth (inches/year)														
	All Events					Up to the First 0.5 inch in Each Event					Excess after the First 0.5 inch of the Larger Events				
	Q1	Q2	Q3	Q4	Annual[1]	Q1	Q2	Q3	Q4	Annual	Q1	Q2	Q3	Q4	Annual
Baseline	5.5	9.9	9.9	6.5	31.8	3.9	5.5	5.2	4.1	18.7	1.6	4.3	4.7	2.4	13.1
CM-s90	6.6	9.7	9.4	7.1	32.8	4.1	5.1	4.7	4.1	18.1	2.4	4.5	4.7	3.1	14.7
CE-s90	6.7	9.8	9.0	7.5	32.9	3.9	5.1	4.6	4.1	17.6	2.8	4.8	4.4	3.4	15.4

[1]Values rounded to one decimal place; therefore, the sum of quarterly values is not always exactly equal to the annual values.

In the climate change scenarios, the frequency of rain events decreased, as shown in Figure 5-1. From the baseline rate of 77 events per year, the frequency decreased to 74 and 70 events per year in the CM-s90 and CE-s90 scenarios, respectively. This decrease was due to fewer small events while the number of large events remained unchanged.

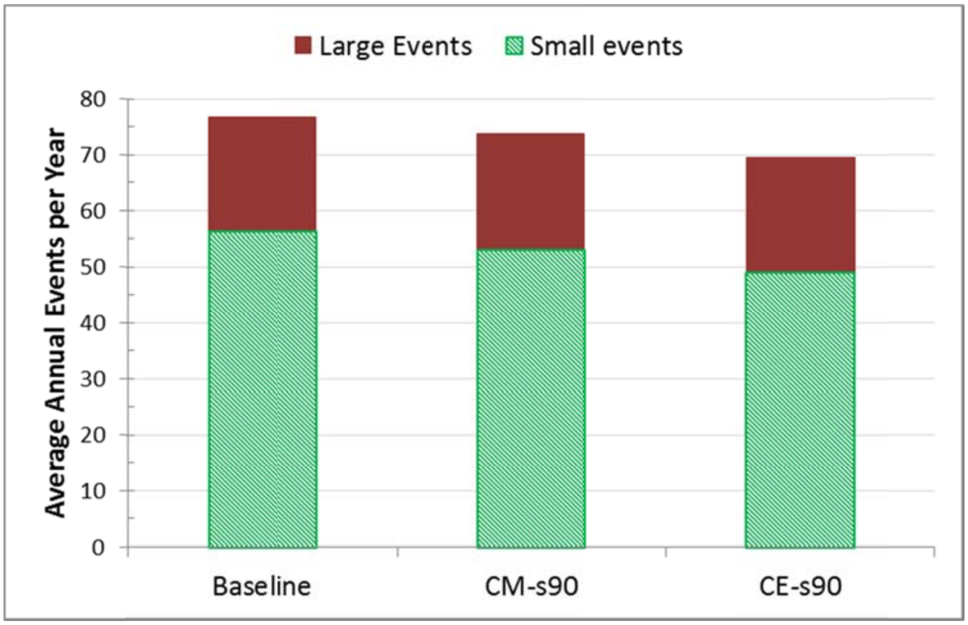

Figure 5-1. Average Number of Precipitation Events Per Year

Throughout the year and when considering all events, the distribution of events by quarter was relatively uniform in the baseline case, ranging from 18 to 21 events per quarter. This is shown in Figure 5-2. There was a decrease in event frequency in the climate change cases in almost all quarters, except for a small increase in the first quarter of the mid-century scenario.

Figure 5-3 shows that when focusing on the larger events, most of the larger events are in the summer quarters, with fewer events in the fall and winter quarters. The baseline scenario has a wider range from the cool months (Q1 and Q4) to the warm months (Q2 and Q3). The climate change scenarios tend to increase the frequency of large events in the cool months and decrease the frequency in the warm months. This means that climate change tends to create a more uniform distribution of large precipitation events throughout the year.

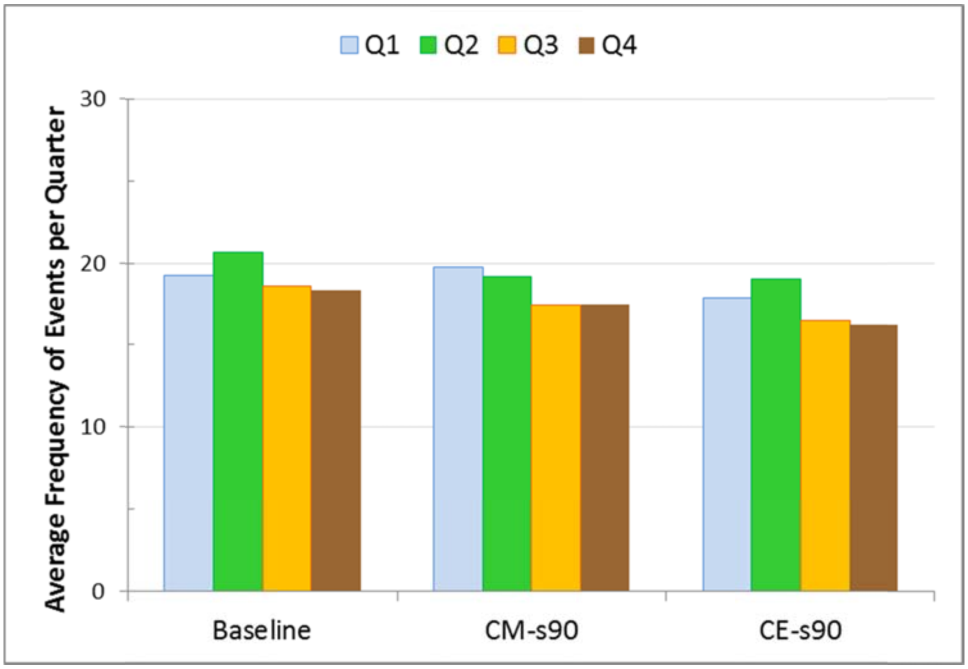

Figure 5-2. Average Number of Precipitation Events per Quarter

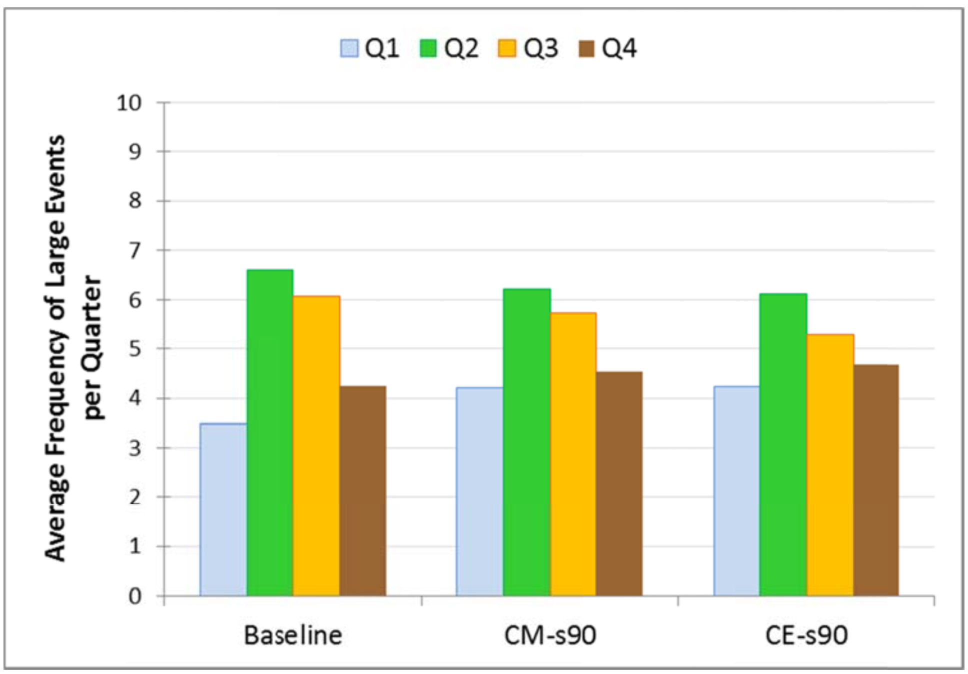

Figure 5-3. Average Number of Large Precipitation Events per Quarter

Figure 5-4 shows that the average annual precipitation depth increased 3% with the climate change scenarios. The increase was because of the additional rain in the larger events. Small events showed a small decrease in average annual amount.

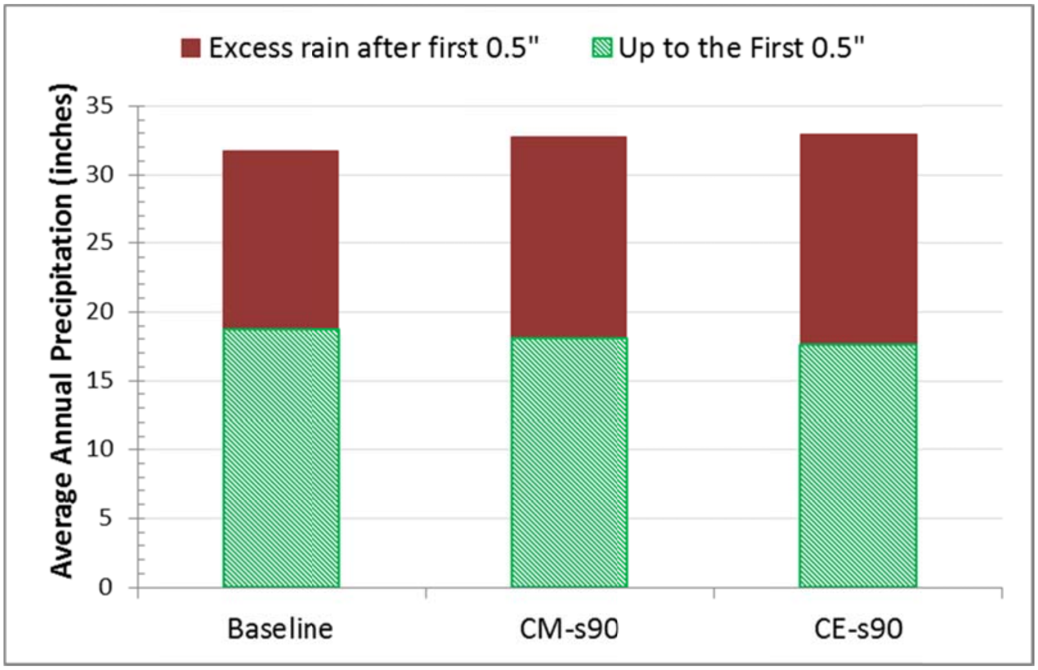

Figure 5-4. Average Annual Precipitation Depth

The quarterly distribution of the average depth of precipitation in the Baseline scenario showed almost twice as much precipitation in the warm months compared to the cool months, as shown in Figure 5-5.

Climate change scenarios showed a decrease in precipitation depth in the summer events (Q2 and Q3) and an increase in precipitation depth in the cool season events (Q1 and Q4). The warm months still had the largest quantity of rain in the climate change scenarios, but the cool months were more wet than in the baseline scenario. Overall the distribution of precipitation across the seasons became more uniform.

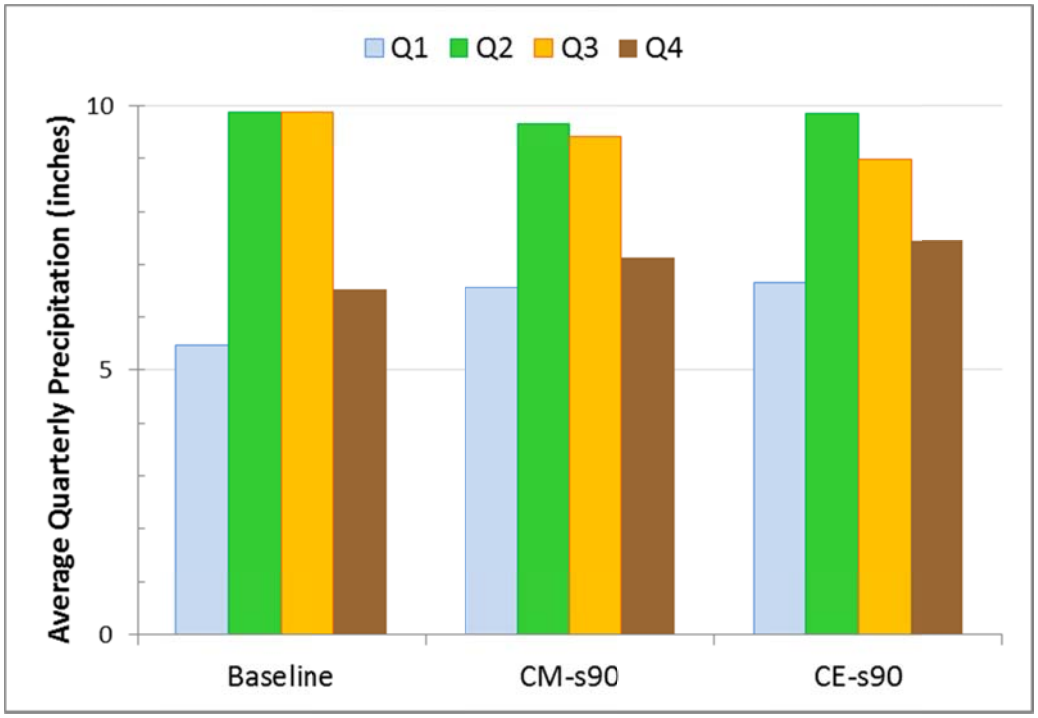

Figure 5-5. Average Depth of Precipitation per Quarter

The evaluation of the baseline and climate change scenarios indicates that more precipitation is likely to fall, but this quantity will be carried in fewer precipitation events. The average annual precipitation increased 3%, but the average frequency of events decreased 9%.

Increases in precipitation were concentrated in the cool months (Q1 and Q4). The decrease in frequency was simulated in all quarters, but more so in the warmer months (Q2 and Q3).

The climate change scenarios showed a more uniform distribution of precipitation. The pattern of dry winters and wet summers that is characteristic of the baseline climate is likely to become less varied if the climate changes. Most of the rain will still fall in the summer months, but the cool months could have more frequent and larger events. This evaluation addressed only the changes in the distribution of precipitation. The implications of climate change on whether precipitation falls as rain or snow are addressed in Section 2.

5.3 Example Storm Events

The previous tabulated results for the average annual statistics show the trends in the simulation results for all events in the datasets. This next section is a discussion of the climate change effects for a few example storm events. The precipitation hyetographs were plotted as graphs in time to compare the three climate scenarios.

Figure 5-6 shows the rainfall intensity during the March 18, 1971 event. This was a large event at the end of the first quarter and the event had a 34-hour duration. The peak rainfall intensity increased from 0.18 inch/hour to 0.26 inch/hour in the CE-s90 scenario as compared to the Baseline scenario.

Figure 5-7 shows the same March 18th event using the cumulative event depth format. The total event depth increased from 1.7 to 2.4 inches in the CE-s90 scenario as compared to the Baseline scenario.

In the Baseline scenario, it took 10 hours to accumulate the first 0.5 inch of rain. The CE-s90 case reached the first 0.5 inch of depth one hour earlier than in the Baseline.

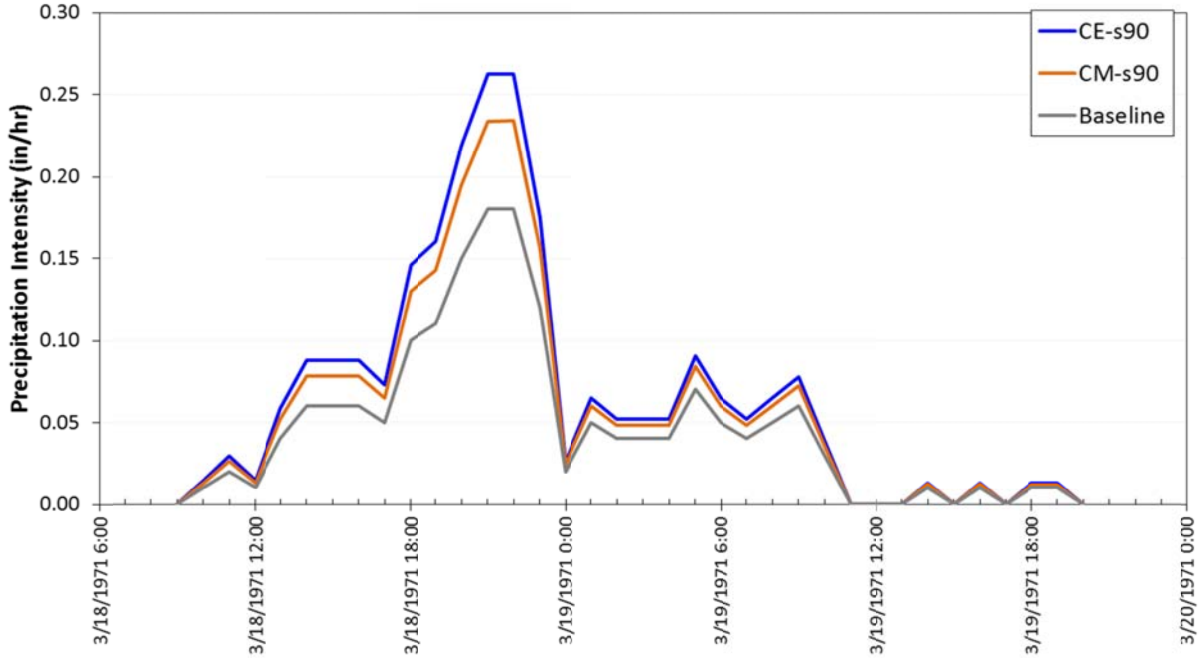

Figure 5-6. Example Storm: Precipitation Intensity - Large Event in the Early Spring

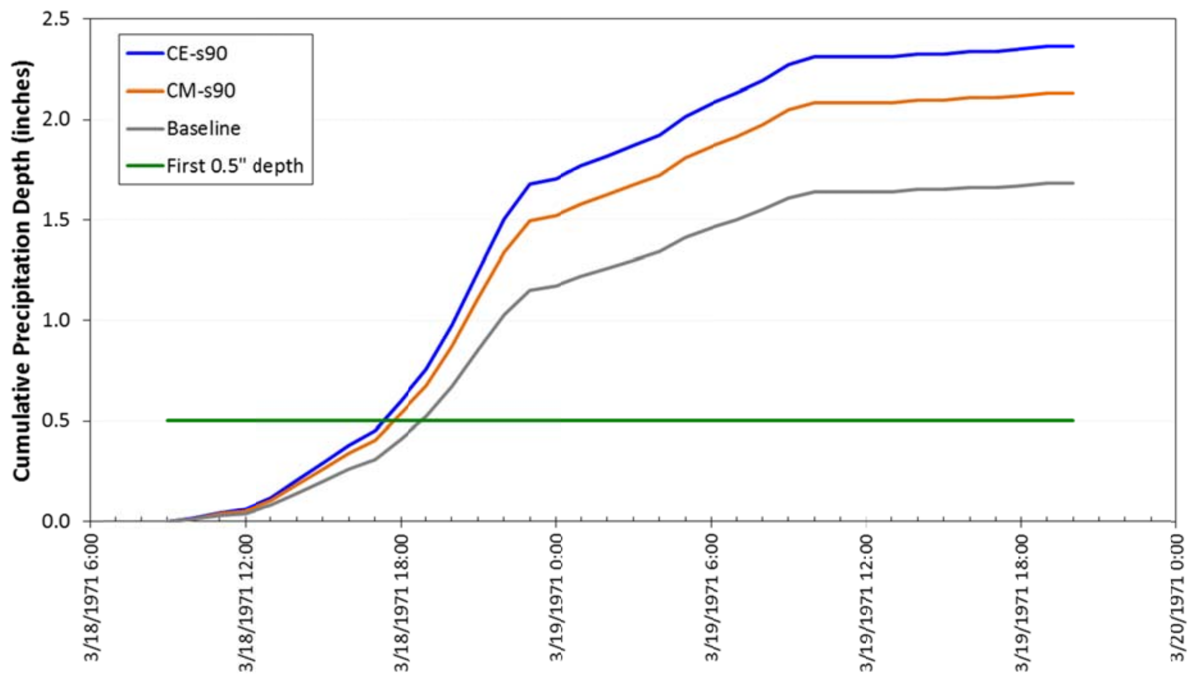

Figure 5-7. Example Storm: Cumulative Precipitation Depth - Large Event in the Early Spring

Figure 5-8 shows a small third quarter event from August 30, 1944. In this example, the cumulative event depth was less in the climate change scenarios. The total event depth decreased from 0.43 to 0.32 inch in CE-s90 as compared to the Baseline scenario. Events of this magnitude are frequent and are the type of event that is intended to be contained by the storage capacity of green infrastructure.

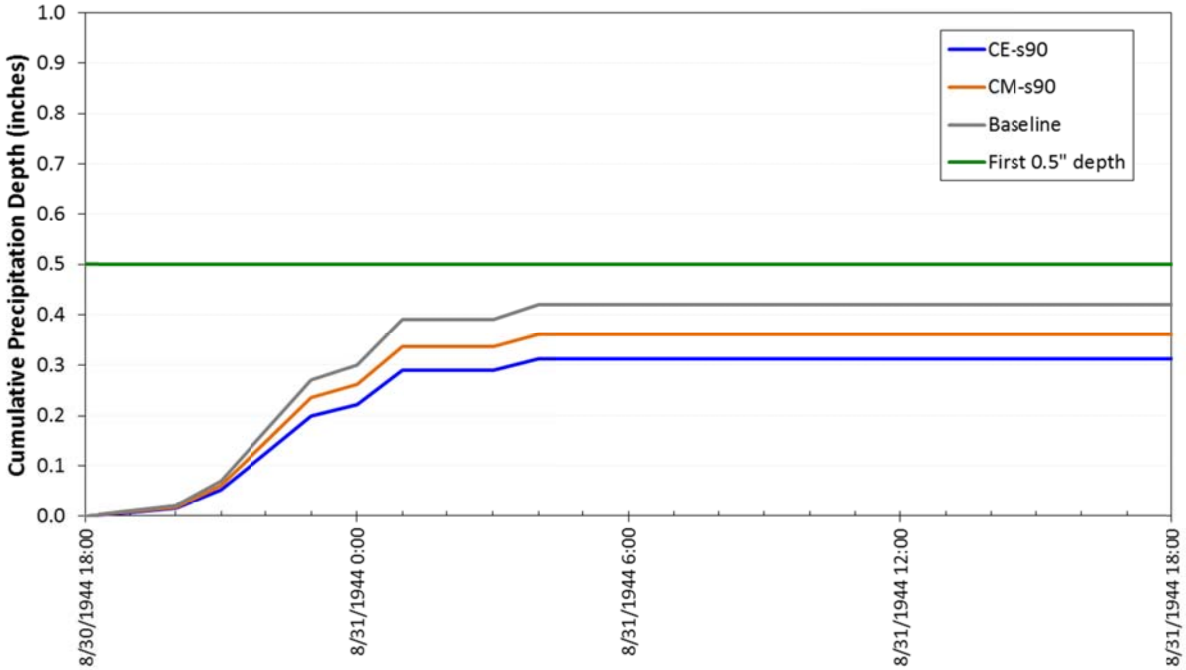

Figure 5-8. Example Storm: Cumulative Precipitation Depth - Small Event in the Late Summer

5.4 Implications for Green Infrastructure

Green infrastructure provides some degree of storage of runoff and pollutants for all wet weather events (large or small). In this evaluation it was assumed that green infrastructure has the capacity to store runoff from the first 0.5 inch of rain during a wet weather event. It was assumed that water in the soil is able to drain or ponded water will evaporate completely between events so that the full capacity of the green infrastructure is available for the next event.

Figure 5-7 is an example of data from a larger wet weather event. For the purpose of this discussion, assume that the precipitation in this March event was in the form of rain. (The performance of green infrastructure during snowfall events was not the focus of this study.) In this event the total depth was 1.7 inches in the baseline scenario and 2.4 inches in the CE-s90 scenario. Green infrastructure would help to manage the first 0.5 inch of rain in each of the climate scenarios. The excess rainfall would be 1.2 additional inches in the baseline and 1.9 inches in the CE-s90 scenario. Stormwater infrastructure would be required to manage the excess rain after the first part is stored in green infrastructure. In this case the excess flow in the CE-s90 scenario would be 11% greater than the baseline scenario. The performance of the green infrastructure would be unchanged by the climate conditions, but the stormwater facilities would need to manage the increase in excess flow. Even though the green infrastructure would operate in a large event equally well in the various climate scenarios, the relative portion of the total event depth stored in green infrastructure would decrease. In this example, the baseline case stored 29% of the event in green infrastructure, while the CE-s90 scenario stored only 21% of the total event depth.

Figure 5-8 is an example of a smaller storm event. In this smaller event, green infrastructure would fully manage runoff because the event depth was less than 0.5 inch. In the baseline scenario the total depth of rain was 0.43 inch; a storm like this would use over 80% of the storage capacity of the green infrastructure facilities. For the CE-s90 scenario the storm event depth was only 0.32-inch; this storm would use only 60% of the green infrastructure capacity.

This pattern, in which small storms become smaller, was characteristic of many of the small storms in the climate change scenarios. Table 5-2 shows this pattern as a reduction in the cumulative depth for the portion of rain less than 0.5 inch. The pattern is also shown in Table 5-1 as a reduced frequency of events with less than 0.5 inch of rain. In the climate change scenarios, small events will still be more frequent than large events and most of the annual rainfall will still be accounted for in the first 0.5 inch of rain. Simulation results imply that green infrastructure will still be effective in dealing with most of the storms and most of the annual rain volume, but the green infrastructure will not be used as fully or as frequently in the climate change scenarios as compared to the baseline scenario.

Therefore, the effective use of green infrastructure is likely to be reduced a small amount by change in the climate patterns. The changes observed in the simulation results are not dramatic. Green infrastructure will still be useful in the management of the majority of storms, but the relative shift in the results implies that green infrastructure will not be as frequently used to the same degree if the climate changes in a manner that is similar to the simulated scenarios used for this evaluation.

The overall variability of weather is much larger than the long-term trends in climate change. Given the multitude of physical factors that influence the performance of green infrastructure, it is unlikely that the small changes simulated in this analysis associated with climate change would be noticed.

Section 6:

Impact of Lower Lake Michigan Level on Jones Island Wood Piles

Many of the structures at the Jones Island WRF are supported by wood piles. A structural evaluation of selected piles during the Water Pollution Abatement Program (Milwaukee Metropolitan Sewerage District, 1980) found some softening of the tops of piles that were not submerged below the groundwater table. Experience in the Milwaukee area has generally shown that wood piles that remain continually submerged in water remain structurally sound, while drying of such piles can lead to deterioration.

Climate change may lead to lower Lake Michigan levels in the future, which could in turn lead to a lowering of the groundwater table on Jones Island. This could result in portions of some piles becoming unsubmerged, leading to structural deterioration. The purpose of this investigation was to identify the general locations of wood piles on Jones Island that may be subject to drying if the level of Lake Michigan decreases due to climate change.

6.1 Pile Elevations

Figure 6-1 shows the assumed locations of wood piles at the Jones Island WRF. To determine the elevations where the wood piles would be vulnerable at the Jones Island WRF, record drawings were obtained from the District for the West Plant Aeration Basins, East Plant Aeration Basins, West Plant Secondary Clarifiers, East Plant Secondary Clarifiers, West Plant Mixed Liquor Channels, return activated sludge (RAS) pipes, and the Breakwall and Dock areas. The record drawings were reviewed to determine the range of cut-off elevations of the wood piles so that these elevations could be compared to the projected groundwater table elevation on Jones Island. The cut-off elevations are summarized in Table 6-1. Appendix E includes the record drawings that were reviewed.

Table 6-1. Wood Pile Cut-off Elevations

Facility	Record Drawing Elevation Range[1]
218 – West Plant Aeration Basins	-11.0
219 – East Plant Aeration Basins	-11.5 to -24.0
221 – West Plant Secondary Clarifiers	-1.0 to -20.17
222 – East Plant Secondary Clarifiers	2.0 to -24.67
213 – West Plant Mixed Liquor Channels	0.0 to -13.75
233 – RAS Pipes Conduits or Channels	-8.75
Breakwall & Dock	6.0 to -25.5

[1]Note: Jones Island Datum, elevations per reference drawings without adjustment to District Datum as noted on drawings.

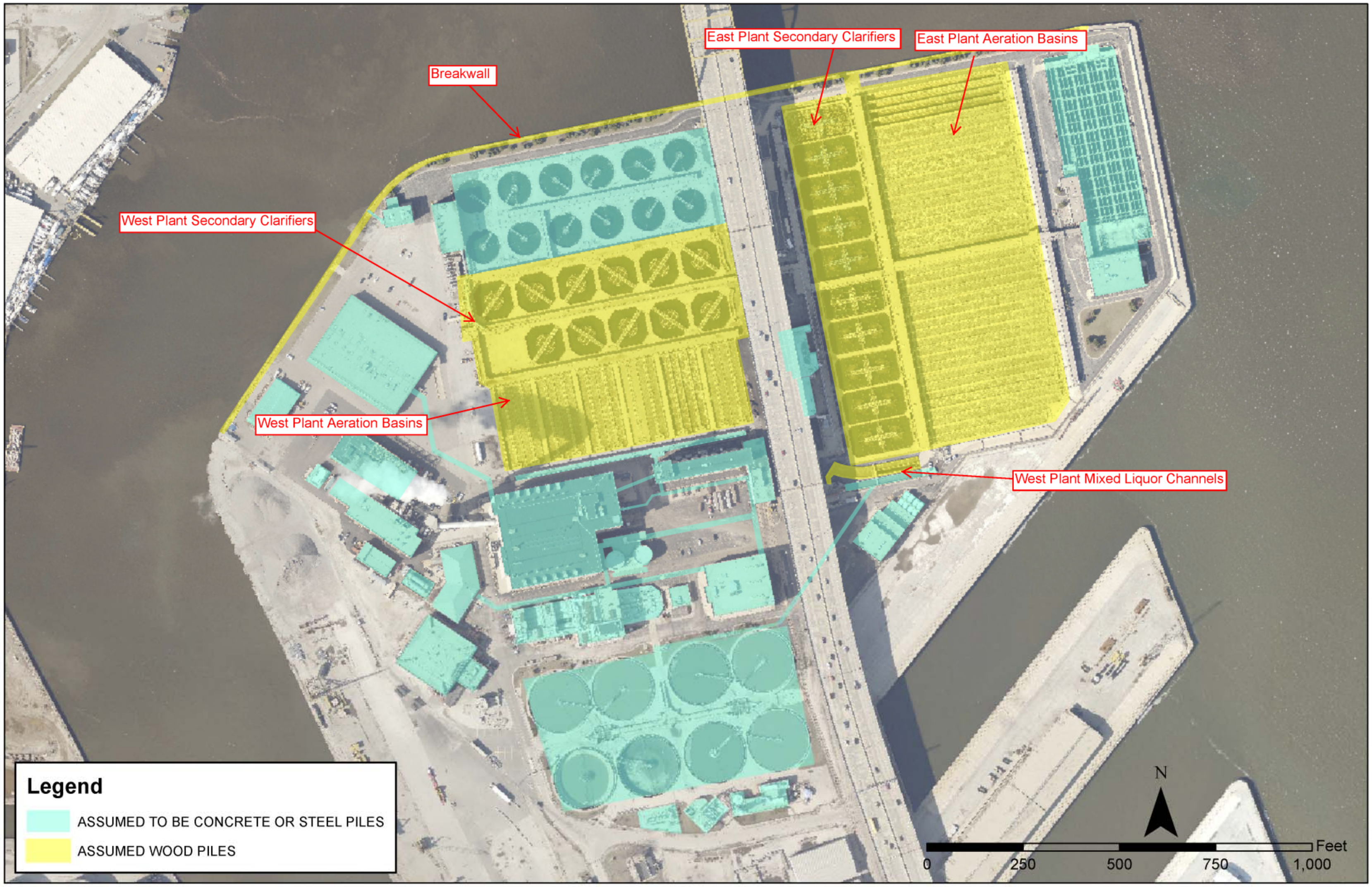

Figure 6-1. Jones Island Water Reclamation Facility – Pile Foundations

Source: Milwaukee Metropolitan Sewerage District

6.2 Water Levels

In order to determine if the wood piles at Jones Island WRF have the potential to become unsubmerged, the historical low Lake Michigan levels and groundwater elevations at the site were reviewed. The International Joint Commission (IJC, 2012) concluded that minimum Lake Michigan levels will likely be within the range of historical lows over the next 50 years, with some additional decrease beyond that time frame.

Lake Michigan reached an all-time low during January of 2013. The minimum level was -2.9 feet, (Jones Island datum). Groundwater water levels measured at Piezometer C22 on Jones Island during January 2013 ranged from -6.1 to -6.6 feet (Jones Island Datum), which is substantially lower than the Lake Michigan level. It is assumed that the groundwater table on Jones Island will fluctuate with changes in Lake Michigan level over time.

Based on this information, it is projected that climate change could lead to a minimum groundwater table elevation on Jones Island on the order of -7 feet (Jones Island Datum). Comparing this elevation to the wood pile cut-off elevations indicates that some of the wood piles at the following facilities could be subject to deterioration due to drying:

- West Plant Secondary Clarifiers
- East Plant Secondary Clarifiers
- West Plant Mixed Liquor Channels
- Breakwall and Dock

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Section 7:

Conclusions and Recommendations

The evaluation of climate change impacts used a number of approaches to identify potential risks for the successful operation of District facilities. This multi-faceted evaluation reached similar conclusions from each of the various methods of evaluation. The patterns in the fundamental data (precipitation and temperature) were reflected in the subsequent simulation results. Based on the results, precipitation changes are more noticeable as a change in distribution rather than an overall increase in the average annual amount. The climate change scenarios show a pattern of increasing precipitation intensity in a few larger events, but a decrease in the size and frequency of many of the smaller events. The month-to-month variation in precipitation, in which the amount has traditionally been concentrated in the summer, is less so in the climate change scenarios. Most of the quantity is still in the summer, but more is expected in the spring and fall, with a small decrease in the late summer.

Temperature changes may be more important than changes in precipitation. The average temperatures are projected to increase in the climate change scenarios, with the highest temperatures in the CE-s90 scenario. Some risk factors are directly tied to the temperature but others are a consequence of the higher rates of PET (potential evapotranspiration) predicted with the temperature change. The average annual PET increased from 29.1 inches/year in the baseline scenario to 47.1 inches/year in the CE-s90 scenario. This increase in annual PET was significantly greater than the change in average annual precipitation, which was 0.9 inch/year greater in CE-s90 than the baseline scenario. Not all of the impacts are adverse to the District's mission. For example, the simulated SSO frequency and volume decreased in the climate change scenarios.

The vulnerability analysis, presented in Section 2, was a broad evaluation of the role of climate change on the overall facilities and operations of the District. This analysis systematically identified groups of environmental factors that may change with climate. These responses were traced to risks impacting District facilities. The risks were ranked using a qualitative system based on the likelihood and confidence that the response will happen and the severity of the impact on facilities. A list of "no regrets" action items was created to identify improvements that would be beneficial whether or not there is a change in the climate.

The following steps are recommended to address the climate change risks identified in this study:

- Undertake "no-regrets" actions as appropriate within current District operations
- Maintain situational awareness of regulatory agency policies that may affect discharge permit conditions
- Maintain situational awareness of potential floodplain reanalysis and remapping
- Evaluate feasibility of modification and develop cost-effective point for the following:
  - Replacement of MIS pump stations with gravity systems to reduce cost of operations
  - Electronic equipment retrofit to provide insulation and ventilation sufficient to mitigate increased air temperatures/heat waves

    - Replacement of WRF equipment to reduce cost of operations
- On an annual basis, compile monitoring data by the District and others and evaluate trends for the following:
    - Energy costs
    - Incidence of power outages
    - Air temperatures
    - Wastewater temperatures in MIS
    - H2S concentration in MIS
    - Lake level
    - Dissolved oxygen in the estuary (real-time monitoring stations in estuary)
- Consider the use of corrosion resistant materials and linings when replacing or rehabilitiating sewers and pump stations and evaluate the need for odor control measures if an increasing trend in H2S is observed.
- Develop a vector management plan that includes monitoring activities, as appropriate
- Every five years analyze District rain gauge data to investigate trends in rainfall/storm intensity, annual rainfall volumes and frequency
- Specifically track changes in vegetation stress, vegetation communities, sediment deposition and scour through observations during annual inspections

Additionally, with every facilities plan update, the items determined in this study should be reevaluated to determine if additional potential impacts have arisen or if the nature of the risk is better understood. Based on this reevaluation, additional opportunities to institute “no-regrets” activities may be identified and the need for adaptation actions may prove to be more pressing.

Section 3 presents the results of the evaluation that quantified the impacts of climate change on the quantity and frequency of SSOs and CSOs, metershed flows, and WRF operations. MACRO model simulations were used to quantify the change in SSOs and CSOs. The results showed that from the baseline scenario to the CE-s90 scenario, CSOs increased in frequency and volume with climate change. Specifically, the simulated CSO frequency increased from 4.1 to 4.5 events per year and the simulated annual CSO volume increased 27%. Most of the changes in CSOs are projected to occur in the spring and fall.

At the same time, average annual SSOs are predicted to decease in frequency and volume. The simulation results showed that SSO volume was 25% less in CE-s90 as compared to the baseline scenario. Not all SSO events were reduced. Some of the larger SSO events increased in size, but the overall trend was fewer SSO events with smaller volumes. The reduction in simulated SSOs is most likely a consequence of the increased PET. As these results are based on calculated values for PET, monitoring actual evapotranspiration would improve the understanding of this environmental parameter, which may be increasingly important in the future.

The FFS model simulations were used to evaluate the change in metershed flows. A flow frequency analysis used long-term simulation results to estimate the peak flow values for recurrence intervals between 1- and 100-years. The 10-year peak flows were tabulated to compare the climate scenarios, as identified in Table D-1 of Appendix D. For many metersheds, the 10-year peak flow values did not change significantly. For those that did change, the increase from the baseline scenario to the CM-s90 scenario was greater than the change to the CE-s90 scenario. The increase in mid-century values was generally no more than 10% greater than the baseline scenario and the increase in end-of-century values was generally no more than 6% greater than the baseline scenario.

To address the potential impacts of climate change on peak flows in the District's wastewater collection, storage, and treatment systems, it is recommended that the District monitor climate change research on changes in precipitation and temperature in southeast Wisconsin. If projected changes are significantly different from current projections, MACRO analyses and metershed analyses for selected metersheds should be updated to assess whether the impact on peak flows is significant.

An evaluation of the impact of climate change on watercourse flows is presented in Section 4. Peak flows are important for managing the floodplains and protecting against flooding, but low flow periods are important for the viability of aquatic life and riparian ecosystems. Flows were evaluated for the Kinnickinnic and Menomonee rivers and changes due to climate were quantified by comparing recurrence intervals ranging from 1- to 100-years. In addition, simulated low flows were evaluated using flow duration curve methods.

For the high flow conditions, the climate change scenarios showed elevated peak flow values as compared to the baseline scenario. The largest change was in the mid-century scenarios for the more extreme recurrence intervals (25- to 100-years). The 100-year flows were up to 16% greater in the CM-s90 scenario than for the baseline scenario; simulated 10-year peak flow values ranged from 6% to 13% greater than those for the baseline scenario. These extreme event peak flow increases will substantially increase the risk of flooding and reduce the level of service currently provided by the District's major flood management investment.

Periods of low flow were quantified using three common statistics used by the EPA. Low flows decreased in the climate change scenarios; the change was in the range of 49% to 73% less than in the baseline scenario. However, the absolute magnitude of changes is small. All three statistical metrics gave the same approximate decrease in flow. Average daily flow did show a significant decrease that will impact aquatic habitat, water quality and aquatic species viability.

The impact of climate change on peak flows should be addressed in future designs of flood management facilities. A risk evaluation is recommended to assess the additional cost for facilities versus the potential cost of additional flood damages if facilities are not designed for the potentially higher peak flows. It is also recommended that the District perform investigations of the impacts of decreased low flows specifically on aquatic habitat, water quality, and aquatic species viability.

The evaluation of precipitation data for event frequency and depth is presented in Section 5. The evaluation was used to infer the impact of climate change on the performance of green infrastructure facilities. More precipitation was simulated in the climate change scenarios, but this quantity was carried in fewer precipitation events. From the baseline scenario to the CE-s90 scenario, the average annual precipitation increased 3%, but the average frequency of events decreased 9%. The increase in precipitation was most noticeable in the cool months (the first and fourth quarters). While the decrease in frequency was simulated in all quarters, it was more pronounced in the warmer months. As a result, the climate change scenarios showed a more uniform distribution of precipitation. The pattern of dry winters and wet summers that is characteristic of the baseline climate is likely to become less varied if the climate changes. Most of the rain will still fall in the summer months, but the cool months could have more frequent and larger events.

Assuming green infrastructure is sized to manage the first 0.5 inch of rain, this analysis evaluated the impact of both large and small rain events on green infrastructure. The frequency of large events (greater than 0.5 inch) were quantified separately from the frequency of small events. Based on the simulation results, it appears that green infrastructure will be effective in dealing with most of the storms and most of the annual rain volume, but green infrastructure will not be utilized as fully or as frequently in the climate change scenarios as compared to the baseline scenario. The changes observed in the simulation results were typically less than 10%. Given the multitude of physical factors that influence the performance of green infrastructure, it is unlikely that the small changes simulated in this analysis that are associated with climate change would be noticed.

As green infrastructure is implemented, it is recommended that the District monitor its effectiveness for various types of rainfall events. With this understanding, the District should reassess the impact of changes in rainfall distributions on those events for which green infrastructure is most effective.

Climate change may result in lower water levels in Lake Michigan. Section 6 presents an investigation of the risk of degradation of wood piles at the Jones Island WRF in response to these lower water levels. Lower water levels in the lake may result in lower groundwater levels on Jones Island, therefore exposing the wood piles to drying and subsequent degradation. The conclusion of this investigation is that some of the wood piles at the West Plant Secondary Clarifiers, East Plant Secondary Clarifiers, West Plant Mixed Liquor Channels, and the breakwall and dock could be subject to deterioration due to drying if Lake Michigan water levels decrease.

It is recommended that the District perform physical inspection of four to six wood piles that have been subjected to drying based on recent low Lake Michigan and Jones Island groundwater levels to assess whether any deterioration has occurred. If deterioration is observed, the District should perform a feasibility study to evaluate mitigation measures, which could include pile reinforcement, implementation of a groundwater recharge system to maintain higher groundwater levels, or consideration of relocation of facilities as part of long-term facilities planning.

Section 8:

References

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United States Environmental Protection Agency (USEPA), Hydrologic Processes: Bankfull Discharge, http://water.epa.gov/scitech/datait/tools/warsss/bankfull.cfm.

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Appendix A: Vulnerability Analysis – Annotated Bibliography

Appendix B: Vulnerability Analysis – Facilities Risk Matrix for Year 2050

Appendix C: Vulnerability Analysis – Facilities Risk Matrix for Year 2010

Appendix D: Conveyance System – Metershed Flow Evaluation

Appendix E: Jones Island Water Reclamation Facility Drawings