Climate Change Preparedness of Great Lakes Communities

Regulatory Permits & Community Planning are based on Outdated Precipitation Data

AUTHORS

Sanjiv K. Sinha, Ph.D., P.E.
Environmental Consulting & Technology, Inc.

Sajani Neeraja
Center for Neighborhood Technology

Thomas H. Price, P.E.
Environmental Consulting & Technology, Inc.

Anna Wolf
Center for Neighborhood Technology

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Lastly, any related communications can be directed to the following.

Sanjiv K. Sinha, P.E., Ph.D. (Project Director)
Environmental Consulting & Technology, Inc. (ECT)
2001 Commonwealth Blvd, Suite 300
Ann Arbor, MI 48105

Email: ssinha@ectinc.com

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Executive Summary

This report examines changing rainfall amounts across five cities in the Great Lakes region and seeks to understand whether the regulatory permits and community planning efforts are aligned with robust and current rainfall estimates. Rainfall amount is a key factor considered in stormwater and sewer infrastructure design and dictates the cost of infrastructure as well as its performance. Over the last few decades, agencies and jurisdictions responsible for infrastructure, including storm and combined sewer infrastructure (much of which was constructed decades ago) have anecdotally reported that event precipitation amounts ("Precipitation Frequency Estimates" or PFEs) have increased significantly. Cities across the region have suffered accordingly. Detroit, for example suffered massive flooding in 2014, 2016, 2019, and 2021, causing economic, environmental, psychological, public health, and financial hardship on residents and businesses. Further, these floods damaged public facilities, museums, and schools across the city. These trends are unfortunately not unique to Detroit, and rampant flooding is now a common occurrence across Great Lakes cities. Finally, forecasts of future event precipitation amounts are significantly more than what they are today, suggesting the impacts of storms and the resulting damages will continue to get worse.

This report's focus is on Milwaukee (Wisconsin), Chicago (Illinois), Detroit (Michigan), South Bend (Indiana), and Buffalo (New York). For the purposes of analyses, the specific geography for each metro area was defined by the service area of their respective water/wastewater utility/agency.

Among our findings, all five wastewater facilities were issued their permits well before the National Oceanic & Atmospheric Administration (NOAA) and Illinois State Water Survey (ISWS) published their most recent precipitation estimates. In other words, wastewater systems were designed to meet past climate trends. While some agencies now require designs based on more recent precipitation estimates, system-wide investments and updates take time and many systems no longer have capacity to meet the needs of our current climate.

Our analyses found that between 1961 and 2020, the City of Chicago has seen nearly a 30% increase in 10-year 24-hour storm PFE, and a 50% increase in 100-year 24-hour storm PFE. Also, MWRD's permit was issued in 2014, and does not use data from the most recent ISWS reports.

Table 1. Timeline for Permit Issuances and Rainfall Related Report Publications

	HISTORICAL RAINFALL DATA	MOST CURRENT RAINFALL DATA	PERMIT ISSUANCE DATE
Milwaukee	1961	2013	2013
Detroit	1961	2013	2008
South Bend	1961	2006	2012
Chicago	1961	2020	2014
Buffalo	1961	2015	2014

Our analyses also found that in most locations, there is little change in the 10-year PFE from historical (1961) to current (2019-2020 timeframe), except in the Chicago region that shows a dramatically large change from the 1961 data. In all cases, the 100-year PFE increased, with increases varying from 11% more rain in Milwaukee to 50% increase in Chicago (Tables 1 through 4).

Table 2. Percent Change in 10-year, 24 hour and 100-year, 24 storm event

	10-YEAR, 24 HOUR PFE CURRENT (CHANGE FROM 1961)	100-YEAR, 24 HOUR PFE CURRENT (CHANGE FROM 1961)
Milwaukee	-4%	11%
Detroit	-5%	14%
South Bend	4%	15%
Chicago	29%	50%
Buffalo	-1%	11%

So far as future projections, for the mid- (and late-) century estimates, both the 10-year and 100-year PFE are expected to increase over the current values. For 10-year events:

- In Detroit: The rainfall amount is expected to increase by 67% by mid-century, and 138% by the end of the century. These are massive changes.
- In Chicago: The rainfall amount is expected to increase by 15% by mid-century, and 20% by the end of the century.
- In Buffalo: The rainfall amount is expected to increase by 10% by mid-century, and 21% by the end of the century.

Due to the passage of FLOODS Law in December 2022, NOAA is now set to provide a national update, and will be required to revise its rainfall data and projections every 10 years. Unfortunately, given the complexity of adding climate change to their analysis, NOAA officials say the earliest the update can be ready is 2026.

Part of the challenge is that every city is using different sources for their climate change estimates. For example, Chicago's estimates were based on the ISWS and, to some degree, ISWS already built climate change into their reporting and therefore show less future change.

Table 3. Projected Future Changes in 10-year, 24 hour storm event

	10-YEAR, 24 HOUR PFE	
	MID-CENTURY (CHANGE FROM CURRENT)	LATE-CENTURY (CHANGE FROM CURRENT)
Detroit	67%	138%
Chicago	15%	20%
Buffalo	10%	21%

For 100-year events:

- In Detroit: The rainfall amount is expected to increase by 19% by mid-century, and over 97% by the end of the century. These are massive changes.
- In Chicago: The rainfall amount is expected to increase by 15% by mid-century, and 20% by the end of the century.
- In Buffalo: The rainfall amount is expected to increase by 22% by mid-century, and 30% by the end of the century.

Table 4. Projected Future Changes in 10-year, 24 hour storm event

	100-YEAR, 24 HOUR PFE	
	MID-CENTURY (CHANGE FROM CURRENT)	**LATE-CENTURY (CHANGE FROM CURRENT)**
Detroit	19%	97%
Chicago	15%	20%
Buffalo	22%	30%

Key recommendations from this report are below:

So far as future rainfall estimates, across the Great Lakes, largest increases are anticipated in Southeast Michigan where a Southeast Michigan Council of Governments (SEMCOG) report predicts a nearly 67% increase by mid-century, and over 138% increase by late-century (10-year, 24-hour storm event).

1. *Combined Sewer Overflow (CSO) permits need to be updated*: Noting the continued increases in rainfall PFEs across the region, regulatory agencies such as the U.S. Environmental Protection Agency (EPA) or state primacy agencies *must* update CSO permits by using the most recent NOAA rainfall estimates in the region, and preferably rely on future estimates instead of the rainfall estimates of "today". Updating the CSO Control Plan to address the impacts of extreme rain events is an important part of managing the risks associated with CSOs.

2. *That "data stationarity" is not relevant anymore, needs to be communicated and accepted among decision makers*: In statistics and hydrology, stationarity refers to the statistical properties of a process that do not change over time. Stationarity is an important concept when analyzing rainfall data, as it helps to determine whether the data can be used to make predictions or be used in statistical models. Unfortunately, as presented in this report, the era of data stationarity (what happened in the past, is a good predictor of what may happen in the future) is now over. Accordingly, infrastructure of today should be designed to be the infrastructure of tomorrow, to continue to provide the intended level of service well into the future.

3. *Legislative reforms are needed to incorporate future climate data:* Recent federal legislation like PRECIP and FLOODS (described later in Chapter 1 of this document) are a step in the right direction, but more direct action is needed from federal and state governments that requires regulated entities like wastewater and stormwater agencies to consider future estimates of precipitation in their CSO Control Plans and planning of current infrastructure. Models estimating climate-driven migration patterns should also be incorporated to better understand future risk.

4. *Legislative reforms are also needed for communities to work closely with the private sector insurance industry:* The protection gap for climate perils such as floods in the future will continue to be a function of the affordability (for the consumer), the rate adequacy (for the insurance industry), and the quality of insurance (for the regulators). If the underlying risk is increasing, so will the premium, thus impacting affordability across a region. Legislative reforms are needed that require communities and insurance industry to work together to understand their risk, mitigate that risk, and get financial resilience with insurance/risk transfer. Regulators must provide oversight to ensure insurance products serve this critical need and customers have adequate information to make informed decisions.

5. *Alternatives to grey infrastructure must continue to be leveraged at large-scale*. These include addressing rain where it falls via the use of green stormwater infrastructure (GSI) across the region. Historically, upgrades to storm water infrastructure meant the use of large and centralized public works projects such as replacement and supplemental interceptor sewers, large conveyance tunnels, and storage reservoirs. While these systems can achieve many goals, they often do not address hyper-local capacity issues, and are very expensive and slow to design and install. GSI has the advantage of reducing the load on the current system, avoiding or reducing the need to replace or expand gray infrastructure while also addressing local capacity issues. In the Great Lakes, Milwaukee Metropolitan Sewerage District's investment of over $50 Million in a public-private partnership based GSI program sets an example that must be replicated across the region.

6. *Options to make existing/future water (green or grey) infrastructure more efficient* must also continue to be leveraged. These include real-time controls, use of artificial intelligence to predict and control flow, state-of-the-art water-efficient technologies, remote leak detection software, and more on-site changes to building codes to prevent site-scale flooding.

7. *Water management strategies must continue to be implemented via public education*: Developing water management plans, adopting water-saving practices, and promoting water conservation through public education can help reduce water consumption and demand, thereby reducing the load in the sewer system.

8. *Emphasis on upgrading infrastructure must be continued*: Replacing aging infrastructure, installing energy-efficient pumps and motors, and adopting smart water management technologies can improve water infrastructure's efficiency and reduce energy consumption.

9. *Funding for water infrastructure in general and green stormwater infrastructure in particular must be dramatically increased,* at the federal and state levels. Even with the passage of the Bipartisan Infrastructure Act, the scale of funding is a very small percentage of what is needed.

Overall, the current and projected increases in PFEs for much of the Great Lakes region's infrastructure are dramatic, and clearly demonstrate the need for investments in infrastructure that are made for mid-century and beyond.

1.0 Introduction

The Great Lakes region has experienced significant variations in extreme rainfall events over the past few decades. According to data from NOAA, the frequency of heavy precipitation events (defined as the top 1% of daily precipitation events) has increased by about 37% in the Great Lakes region since the early 20th century. In recent years, the region has experienced several extreme rainfall events, including the severe storms that caused widespread flooding in parts of Michigan in June 2021 and the heavy rainfall that caused flooding in Toronto in July 2013. These events underscore the increasing risk of extreme weather events in the region.

Climate models suggest that extreme rainfall events are likely to become more frequent and intense in the Great Lakes region in the coming decades, as a result of climate change. This could lead to increased flooding, erosion, and other hazards, particularly in urban areas where infrastructure is not designed to handle such events.

As climate change impacts grow increasingly severe in the Great Lakes region, many communities are faced with the challenge of updating aging infrastructure to mitigate associated risks, including flooding and water quality impairments. However, a barrier to communities making adequate investments in their stormwater infrastructure systems is the use of outdated precipitation/rainfall data in stormwater, combined sewer, and flood control design and water quality improvements. Improvements to meet regulatory and court mandated requirements and watershed-based plans should be designed using *future* precipitation data that considers any increases in large precipitation events based on climate change projections. Other infrastructure impacted by precipitation events

2022 PRECIP and FLOODS Laws of the United States (U.S.) Congress

Directly aligned with the thesis of this report, the federal government also recognizes that the U.S. faces increasing precipitation, that much of our existing infrastructure is not equipped to meet these extreme events, and that timely data gathering and sharing, along with risk communication can help prepare our communities from the worst impacts. At the conclusion of the 117th Congress, President Biden signed into law two bipartisan bills that will support NOAA's critical work to monitor, forecast, and communicate about floods and hurricanes, and will further the agency's use of forward-looking, timely data to inform state and local planning.

The Providing Research and Estimates of Changes In Precipitation (PRECIP) Act directs the NOAA to update probable maximum precipitation estimates for the United States within 10 years and make them publicly available. In addition, NOAA will develop a national guidance document that provides best practices for federal and state regulatory agencies, private meteorological consultants, and other users that rely on precipitation estimates.

The Flood Level Observation, Operations, and Decision Support (FLOODS) Act sirects NOAA to establish a National Integrated Flood Information System to inform and provide timely decisions to reduce flood-related impacts. The bill requires NOAA to take several actions, including establishing partnerships with educational institutions and federal agencies, that improve the forecasting and the communication of flood, tornado, and hurricane events. Additionally, the bill establishes an Interagency Committee on Water Management and Infrastructure to ensure that federal agencies that have joint or overlapping responsibilities on water-related matters are working together.

By providing better rainfall data, these laws will help communities make smart investments in flood-resilient infrastructure in the face of stronger storms and more frequent flooding.

such as roads, highways, bridges, and real estate developments should also consider the potential impacts of climate change.

Extreme rainfall events and flooding are expected to continue to cause erosion, poor water quality, and negative impacts on transportation, agriculture, human health, and infrastructure[1] . Precipitation in the Midwest is greatest in the east, declining towards the west. Precipitation occurs about once every seven days in the western part of the region and once every three days in the southeastern part. The 10 rainiest days can contribute as much as 40% of total precipitation in a given year. Generally, annual precipitation increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls. This tendency towards more intense precipitation events is projected to continue in the future.

To address these challenges, cities and communities in the Great Lakes region are implementing a variety of measures to manage stormwater and reduce the risk of flooding. These include GSI techniques such as rain gardens and bioswales, permeable pavement, and stormwater detention basins. They are also implementing real-time monitoring and data analysis to better understand and manage stormwater and improve the efficiency of their stormwater management systems.

However, continued efforts will be needed to adapt to the increasing risk of extreme rainfall events in the Great Lakes region. This will require ongoing investment in infrastructure upgrades, GSI, and other measures to manage stormwater and reduce the risk of flooding and other hazards. It will also require collaboration and coordination among stakeholders, including government agencies, communities, and private sector partners.

In December 2022, Senator Sherrod Brown of Ohio, introduced the Excess Urban Heat Mitigation Act, a legislation to create a grant program through the Department of Housing and Urban Development (HUD) that allows entities such as local governments, metropolitan planning organizations, tribal governments, and nonprofits to apply for funding to implement efforts to help offset the effects of excess urban heat, such as cool pavements, cool roofs, tree planting and maintenance, green roofs, bus stop covers, cooling centers, and local heat mitigation education efforts.

The research documented in this report seeks to define the level of precipitation frequency increase associated with large storms to help Great Lakes communities and agencies better understand how well equipped their infrastructure systems may be to meet current and future needs and identify areas that would benefit from additional GSI investments. To understand the range of conditions in the Great Lakes region, the following data was reviewed:

- The year when the National Pollution Discharge Elimination Program (NPDES) permits and/or long-term control plans (LTCPs) were approved for the respective wastewater agencies;
- Historical precipitation data that these permits used to inform infrastructure investment needs;
- Current precipitation data for these communities;
- Future precipitation estimates (where available); and
- Levels of GSI investment in each community.

[1] Climate Change Impacts in the United States: The Third National Climate Assessment,

2.0 Communities Under Review

For this report, the larger and geographically dispersed Great Lakes cities of Chicago (Illinois), Buffalo (New York), Detroit (Michigan), Milwaukee (Wisconsin), and South Bend (Indiana) were selected. The regions associated with these cities were selected for two main reasons. First they are a subset of the communities located in counties identified in an earlier report Climate Risks and Opportunities in the Great Lakes Region by *Resilient Infrastructure Sustainable Communities*, as top candidates for GSI investment, based on a combination of climactic, social, and financial factors. And secondly, all five cities are located in different Great Lakes States with population sizes that range from 100,000 to several million.

A word on sewer systems
With the exception of very rural communities, most cities and suburbs in the U.S. have a combined sewer system (CSS), a municipal separate storm sewer system (MS4), or a combination of systems. A CSS is one in which the sewer infrastructure collects both sewage and stormwater and conveys it to the wastewater treatment plant (WWTP). Under dry weather conditions, the CSS system conveys wastewater entering the system to the wastewater treatment plan (WWTP). Under wet weather conditions, the CSS also collects and conveys stormwater. During large storm events, the system may be overwhelmed, resulting in “overflow” to receiving waterways (e.g., into a local river or stream) at certain points throughout the system before reaching the WWTP. These combined sewer overflow (CSO) points are regulated by the EPA through the NPDES permits (renewed every five years), and, per the EPA’s 1994 CSO Control Policy, communities with CSS’s are required to create a long-term control plan to reduce the number of overflow points and frequency of overflow incidents.

Table 5. Communities Reviewed in this Report

CITY	WASTEWATER AGENCY	AGENCY SERVICE AREA	MUNICIPAL AREA	POPULATION (2019)
Chicago, IL	Metropolitan Water Reclamation District of Greater Chicago	884 mi^2	227 mi^2	2.71 million (Chicago) 5.9 million (Cook County MWRD’s jurisdiction)
Buffalo, NY	Buffalo Sewer Authority	110 mi^2	40 mi^2	256,480 (Buffalo) 550,000 (BSA)
Detroit, MI	Detroit Water & Sewerage Department	140 mi^2	140 mi^2	674,841 (Detroit)
Milwaukee, WI	Milwaukee Metropolitan Sewerage District	423 mi^2	96 mi^2	594,548 (Milwaukee) 1.1 million (MMSD)
South Bend, IN	South Bend Department of Public Works	42 mi^2	42 mi^2	102,037 (South Bend)

Conversely, MS4s, as the name suggests, are comprised of two separate systems, one collecting municipal sewage, the other collecting stormwater. The sewage is conveyed directly to the WWTP and the stormwater is discharged into receiving waterways. Within larger metropolitan areas, these systems are permitted through the NPDES but are not subject to the CSO Control Policy. Some communities with CSS’s have implemented measures such as sewer separation and installation of large tunnels to intercept overflows to reduce the number of CSO events, a process that is costly and time intensive.

3.0 Data Sources and Methodology

PFEs are used as the basis of design for sewer systems and other surface water impacted infrastructure. Each of the five sewer agencies, presented in Table 5, adhere to their respective state's official standards for infrastructure design. However, in all cases, the PFEs have been updated since the long-term control plans were prepared. Using each city's sewer agency service area, the volume of precipitation for 10-year and 100-year storms were calculated for both historical and current precipitation standards. This was used to develop a past/present estimate for the volume of precipitation that communities planned and designed for.

4.0 Regulatory Context and Green Infrastructure Investment

Historically, LTCPs and other stormwater management projects relied heavily on centralized gray infrastructure strategies, such as expanded pipes, tunnels, and reservoirs, or even converting parts of the CSS to an MS4. While these systems can be effective in reducing combined sewer overflows, they often provide little relief from basement back-ups and surface flooding. In addition, gray infrastructure systems are expensive and take a long time to design, approve, and construct. As a result, over the last two decades, many agencies have started using distributed GSI systems that reduce the load on gray infrastructure system thus reducing or eliminating the need for expansion of those systems while also providing relief from localized basement and street flooding. Recognizing the life-cycle cost savings benefit of GSI strategies and the aligned community benefits. EPA issued policy memos, beginning in 2007, that provide guidance on integrating GSI into NPDES permits and LTCPs.

Table 6 presents the year of the most recent municipal NPDES permit or the year(s) of a community's finalized consent decree. The dates of these documents provide an indication of the likely PFEs the community relies on for the infrastructure design. The table also indicates when a community began including GSI as a part of its regulatory compliance effort, and how much GSI the communities have implemented in terms of areas or volumes and dollars.

The MWRD of Greater Chicago's consent-decree was finalized in early 2014 and documented the agency's commitment to GSI. MWRD released its GSI plan in 2015 and in 2017 MWRD started its call for projects. Between 2014 and 2020, the agency has installed nearly 59 million gallons (MG) of stormwater volume (design retention capacity as defined by MWRD) and has spent $17M on its *Space to Grow* program (a partnership between MWRD, Chicago Public Schools [CPS], the Chicago Department of Water Management, Open lands, and the Healthy Schools Campaign to implement GSI on schoolyards); $6M in rain barrels, and $3.1M on other green infrastructure projects in various communities.

The Buffalo Sewer Authority's (BSA) first consent decree/LTCP was finalized in 2004 and focused on sewer separation, CSO regulator optimizations, and supplemental capacity projects. The Department revised its consent decree in 2014, this time prioritizing real time control technology, additional sewer patrol point optimizations, and green infrastructure. BSA committed to spending $380M over 20 years on projects (gray and green) aimed at reducing combined sewer overflow events. The city's stormwater masterplan, RainCheck, was initiated in 2015 and updated in 2019. As of 2019, BSA reports that 1,047 acres are managed by GSI, including 649 acres of impervious surface have been reduced, and 952 MG of runoff prevented from entering sewer systems in a typical year.[2] [3] [4]

Detroit Water & Sewerage Department's (DWSD) 1977 consent decree did not specify the use of GSI and while the document hasn't been formally updated, the stormwater management strategies have evolved, pursuant to NPDES permit requirements. In 1996, DWSD's CSO control plan was finalized and paved the way for the incorporation of GSI in its 2008 updates. Between 2008 – 2011, DWSD

[2] https://regional-institute.buffalo.edu/wp-content/uploads/sites/155/2021/07/RainCheck1_0_Report-1.pdf
[3] https://bit.ly/BuffaloSewer_LTCP
[4] https://bit.ly/BuffaloSewer_LTCP-Appendices

revised its CSO programs to include GSI specifically to save money in the immediate aftermath of the Great Recession. In 2013, DWSD developed its GSI plan to manage 17 outfalls along the Rouge River, with a goal to spend $50M by 2029 on a range of GSI projects. DWSD has removed approximately 130 MG of water from the sewer system and has spent nearly $30M on a variety of GSI projects between 2013 and 2021. [5] [6]

Milwaukee's sewer system, managed by the Milwaukee Metropolitan Sewerage District (MMSD), updated its WPDES permit (Wisconsin pollution discharge elimination system). As early as 2013, MMSD had been incorporating GSI into their permitted capital planning and as of 2019 they've increased their plan for volumetric capture to 50 MG, 20 MG of that being within the combined sewer area.[7] [8]

South Bend finalized its 2012 consent decree/LTCP with no specified commitments to GSI, however the City did install smart-sewer rain gauges which have been instrumental in operating their systems based on hyperlocal precipitation, real time data. The City experienced cost constraints during implementation of the original consent decree and updated it to include more GSI strategies. The most recent consent decree/LTCP was finalized in 2021 and includes 9 GSI projects and an overall LTCP cost reduction from $700M to $250M. [9] [10]

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[5] https://detroitmi.gov/sites/detroitmi.localhost/files/2021-06/FINAL%20DWSD%20GSI%20Annual%20Report%20April%201%202021_Formatting%20edited.pdf
[6] https://www.glwater.org/wp-content/uploads/2020/12/Full_WWMP_Report_Final_June-2020.pdf
[7] https://greatlakes.org/wp-content/uploads/2020/09/AGL_GSI_CaseStudy_Milwaukee_FIN.pdf
[8] 2019 permit: https://www.mmsd.com/application/files/6316/2937/8882/MMSD_Permit_FINAL_signed_WEB.pdf
[9] https://www.epa.gov/sites/default/files/documents/cityofsouthbend-cd.pdf
[10] 2021 CD and LTCP: https://centerforneighborhoodtech-my.sharepoint.com/:b:/g/personal/awolf_cnt_org/ETb5uNKN59ZHsXvX_0IW4BIBMeHFWvj-2AV3zmniaXl49A?e=KI4GQu

Table 6. Municipal Permit/Regulatory Requirement

	Chicago, IL[11] [12] [13]	Buffalo, NY	Detroit, MI	Milwaukee, WI	South Bend, IN
Agency	MWRD	BSA	DWSD	MMSD	SBDPW
Regulatory Boundary	Cook County, IL	City of Buffalo	City of Detroit	Milwaukee County, WI	City of South Bend
Regulatory document(s) (NPDES permit or Consent Decree/LTCP) that first mention GSI	Consent Decree Civil Action No. 11 C 8859. Negotiations began in 2012 and were finalized on January 6, 2014.	Consent Decree Civil Action. Finalized in 2004, with no mention of GSI. BSA's Consent Decree was updated and finalized in 2014 - focused on real time control, additional sewer patrol point optimizations, and GSI.	DWSD's 1977 consent decree did not reference GSI specifically. While the document hasn't been formally updated, the stormwater mgmt. strategies have evolved, pursuant to NPDES permit requirements. In 1996, DWSD's CSO control plan was finalized and paved the way for the incorporation of GSI in its 2008 update.	Wisconsin PDES, 2013 permit contains first mention of GSI.	Preliminary consent decree was finalized in 2012, without any mention of GSI. However, South Bend recently finalized a revision to its consent decree/LTCP – its *Smarter Alternative for a Greener Environment* (SAGE) plan was finalized in 2021 and strategically incorporates GSI throughout the community.
Date(s) documents are updated, if applicable	N/A	N/A	Between 2008 - 2011 DWSD revised its CSO programs to include GSI to save money.	2014 version renewed 2013 permit; Most recent permit was renewed in 2019.	N/A
GSI commitments (where available)	Starting in 2017: MWRD implemented a GSI Call for Projects (to which communities can apply for funding); MWRD also participates in *Space to Grow* - which installs GSI on CPS land.	In the 2014 LTCP, BSA committed to spending $380M over 20 years in infrastructure improvements and the Authority estimates 24% ($92M) of this will be spent on GSI. BSA aims to convert 1,315 acres to GSI.	DWSD has a GSI plan for 17 specific outfalls along the Rouge River, with a goal to spend $50 M by 2029 on a range of GSI projects.	2014 WPDES permit states an increased GSI retention goal from 1 MG to 12 MG of capture. The April 2019 permit (which expires March 2024) increases GSI retention to 50 MG with 20 MG	The SAGE plan includes 9 GSI projects, and a reduced number of committed CSO storage tanks from 7 in the original LTCP to 4. The city estimates the overall LTCP costs will be reduced from $700M to $250M.

[11] https://mwrd.org/sites/default/files/documents/ConsentDecree_AnnualReport_210325_web.pdf
[12] https://mwrd.org/stormwater-management-1
[13] https://www.leagle.com/decision/infdco20120809d06

	Chicago, IL[11] [12] [13]	Buffalo, NY	Detroit, MI	Milwaukee, WI	South Bend, IN
				collected within the combined sewer area.	
GSI progress (acreage or sq footage)	Between 2014 and 2020: 58 MG of stormwater (design) retention capacity.	1,047 acres managed by GSI 649 acres of impervious surface reduced 952 MG of runoff prevented from entering sewer systems in a typical year.	To date, DWSD is managing 117 acres using GSI (that's 62 MG stormwater retained annually) And has removed approximately 130 MG of water from the sewer system.	Capacity of GSI = 61.7 MG - Top categories include 34.2 MG in bioswales, 9.9 MG in rainwater catchment, - 7.2 MG in wetlands (natural or constructed).	Unclear what progress has been made.
GSI progress (dollars invested)	$17 M for Space to Grow program since 2014; $6M in rain barrels since 2014; $3.1 M in other green infrastructure projects in various communities.	Unclear what BSA has spent thus far	Between 2013 and 2021, DWSD has spent nearly $30 million on a variety of GSI projects.	Total money spent (by MMSD & partners) $90.9 M.	Unclear what progress has been made.

5.0 Changing Precipitation Frequency Estimates

Most communities in Midwestern states have historically relied on the NOAA for their PFE, including all five cities studied here-in. This began in 1961 when NOAA published Technical Paper 40, which contained rainfall depths for storms of significant return periods and durations for the entire U.S. NOAA did not release updated estimates until 2004, known as Atlas 14. After the publication of Atlas 14, many jurisdictions started using Atlas 14 data for their PFEs, including the cities of Milwaukee, Detroit, and South Bend. However, Chicago and Buffalo have continued to use other publications for their PFEs.

Table 7 shows the PFE data sources currently being used for design by each community, and Table 8 shows the latest 10-year and 100-year rainfall amounts from both NOAA and other applicable data sources. In Table 8, the data source used for design by each is listed first and the additional data source(s) are listed second. The paragraphs following the tables provide further discussion regarding the various data sources.

Table 7. Data Sources for Design PFEs

Waste Water Utility Region	Source	Agency	Data Range
Milwaukee, WI	Atlas 14 Vol 8	NOAA	2012
Detroit, MI	Atlas 14 Vol 8	NOAA	2012
South Bend, IN	Atlas 14 Vol 2	NOAA	2000
Chicago, IL	Bulletin 75	ISWS	2017
Buffalo, NY	Atlas 14, Vol 10	NOAA	2013

Table 8. Changing Rainfall Estimates Across the Region

City	10-yr, 24-hr storm (in)	100-yr, 24 -hr storm (in)	Source	Publication Year
Milwaukee, WI	3.75	6.08	NOAA Atlas 14 Vol 8, 2.0	2013
Milwaukee, WI	3.86	6.24	ISWS Bulletin 71	1992
Detroit, MI	3.31	5.13	NOAA Atlas 14 Vol 8, 2.0	2013
Detroit, MI	3.13	3.60	ISWS Bulletin 71	1992
South Bend, IN	4.09	6.27	NOAA Atlas 14 Vol 2, 3.0	2006
South Bend, IN	4.00	6.54	ISWS Bulletin 71	1992
Chicago, IL	5.15	8.57	ISWS Bulletin 75	2020
Chicago, IL	4.47	7.58	ISWS Bulletin 70/71	1989/1992
Chicago, IL	4.29	6.95	NOAA Atlas 14 Vol 2, 3.0	2006
Buffalo, NY	3.48	5.32	NOAA Atlas 14 Vol 10, 3.0	2015
Buffalo, NY	3.17	5.33	Extreme Precipitation in New York and New England	2011

The official state guidance for stormwater design for the States of Wisconsin and Michigan indicate that the most current NOAA Atlas 14 estimates for their region shall be used for engineering design. It was confirmed that Milwaukee and Detroit adhered to this protocol.

In 2015, the Purdue Research Foundation released an updated Stormwater Drainage Manual that included PFEs for select cities in Indiana, one of which was South Bend. These estimates were based on NOAA Atlas 14 data.

Due to numerous exceedances of the Technical Paper 40 PFEs, the ISWS conducted its own analysis and published it as Bulletin-70 in 1989. Bulletin 70 utilized precipitation gages throughout the state with data through 1983. Although there was a slow start, most agencies in Illinois eventually adopted Bulletin 70 for stormwater design. Due to concerns with Technical Paper 40 throughout the Great Lakes, the ISWS expanded their analysis to include the states of Minnesota, Iowa, Missouri, Wisconsin, Michigan, Indiana, Kentucky, and Ohio as published in Bulletin 71 in 1992. For Illinois, there was no change between Bulletin 70 and Bulletin 71. Prior to the release of NOAA Atlas 14, Bulletin 71 was used to varying degrees in the studied states. Since the release of Atlas 14, many states have converted to using that source, but Illinois continues to use the ISWS PFE. In 2020, the ISWS released Bulletin 75, which is an update of Bulletin 70 using precipitation data through 2017. The Bulletin 75 study was limited to the State of Illinois and most jurisdictions in Illinois are currently using Bulletin 75.

In addition to the differences in data periods between Atlas 14 and Bulletin 70 and 75, there are differences in statistical methods that were used. The most notable difference is that Bulletin 70 and 75 included a non-stationarity factor to account for increases in precipitation amounts during the period of record and Atlas 14 did not. The adjustment factor for 24-hour rainfall events ranged from 0.96 to 1.11 and the adjustment factor for Northeast Illinois, where MWRD's service area is located, was 1.06 for both Bulletin 70 and 75.

New York State also conducted their own analysis. The study and web tool "Extreme Precipitation in New York and New England" was a joint effort between the Northeast Regional Climate Center (NRCC) and the New York State Energy Research and Development Authority (NYSERDA). Published in 2011, it calculated precipitation amounts for major design storms in New York State and explicitly stated that a motivation was to obtain more recent estimates for planning and design than Technical Paper 40. This analysis included data through 2008. Since the publication of Atlas 14 Volume 10 for Northeastern States in 2015, the online web tool has been updated with the same data used by NOAA for New York State. As of January 2015, the New York State Stormwater Management Design Manual considers either of these sources as acceptable for infrastructure design.

Tables 9 through 13 and associated Figures 1 though 5 show 10-year and 100-year rainfall amounts for the five study geographies from the various data sources relevant to each. The precipitation amounts are expressed in inches as well as the equivalent gallons for the service area of the agency. It should be noted that TP40 provides rainfall amounts for various frequencies and durations via isohyet maps and no tabular data is provided for specific cities. Thus, the rainfall depths for each city were interpolated from the maps; therefore, the amounts in the tables below are given to the nearest 0.1 inch. Within the other data sources, tabular rainfall depths are provided to the nearest 0.01 inch and that level of precision is carried through to the tables below.

Table 9. Changing Rainfall Estimates in Milwaukee

Source	Agency	Publication Year	Data source Spatial Extent	10-yr, 24-hr storm (in)	100-yr, 24-hr storm (in)	10-yr, 24-hr storm vol (MG)*	100-yr, 24-hr storm vol (MG)*
Technical Paper 40	NOAA	1961	United States	3.9	5.5	28,670	40,432
Bulletin-71	ISWS	1992	Midwestern States	3.86	6.24	28,376	45,871
Atlas 14 Vol 8, Version 2.0	NOAA	2013	Midwestern States	3.75	6.08	27,567	44,695

* Rainfall over MMSD service area of 423 sq mi.

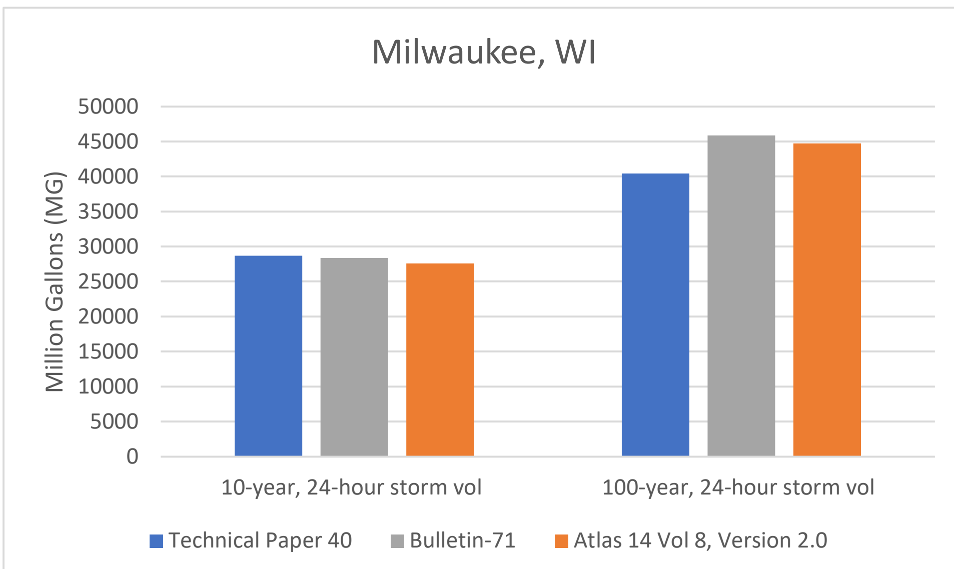

Figure 1. Changing Rainfall Estimates in Milwaukee

As can be seen from Table 9 and Figure 1, between 2013 and 1961, Milwaukee area 10-year rainfall amount is slightly lower. However, over the same time period, for the 100-year rainfall is higher by nearly 0.6 inches.

Table 10. Changing Rainfall Estimates in Detroit

Source	Agency	Publication Year	Data source Spatial Extent	10-yr, 24-hr storm (in)	100-yr, 24-hr storm (in)	10-yr, 24-hr storm vol (MG)	100-yr, 24-hr storm vol (MG)
Technical Paper 40	NOAA	1961	United States	3.5	4.5	8,491	10,917
Bulletin-71	ISWS	1992	Midwestern States	3.13	4.36	7,593	10,577
Atlas 14 Vol 8, Version 2.0	NOAA	2013	Midwestern States	3.31	5.13	8,030	12,445

***** Rainfall over DWSD service area of 140 sq mi.

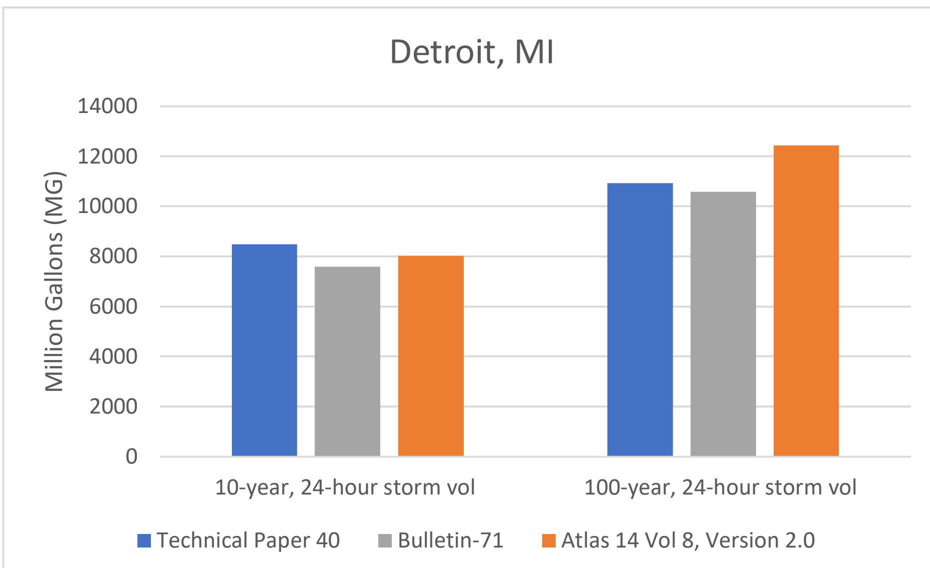

Figure 2. Changing Rainfall Estimates in Detroit

As can be seen from Table 10 and Figure 2, between 2013 and 1961, Detroit area 10-year rainfall amount is slightly lower. However, over the same time period, for the 100-year rainfall is higher by nearly 0.63 inches.

Table 11. Changing Rainfall Estimates in South Bend

Source	Agency	Publication Year	Data source Spatial Extent	10-yr, 24-hr storm (in)	100-yr, 24 -hr storm (in)	10-yr, 24-hr storm vol (MG)	100-yr, 24-hr storm vol (MG)
Technical Paper 40	NOAA	1961	United States	3.9	5.4	2,847	3,941
Bulletin-71	ISWS	1992	Midwestern States	4.00	6.54	2,920	4,774
Atlas 14 Vol 2, Version 3.0	NOAA	2006	Ohio River Basin and Surrounding States	4.06	6.23	2,963	4,547

* Rainfall over SBPW service area of 42 sq mi.

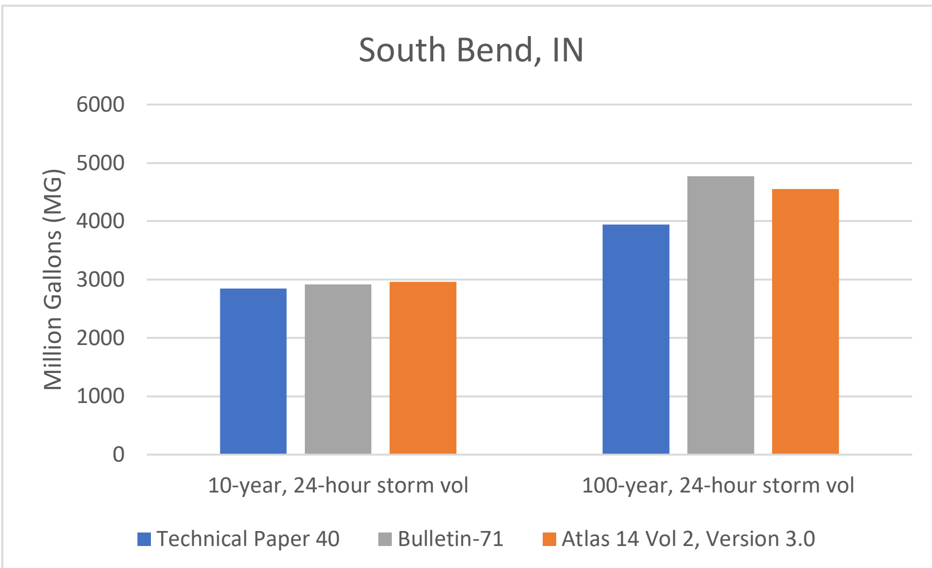

Figure 3. Changing Rainfall Estimates in South Bend

As can be seen from Table 11 and Figure 3, between 2006 and 1961, South Bend area 10-year rainfall amount shows a small increase of 0.16 inches. However, over the same time period, for the 100-year rainfall is higher by nearly 0.83 inches.

Table 12. Changing Rainfall Estimates in Buffalo

Source	Agency	Publication Year	Study Spatial Extent	10-yr, 24-hr storm (in)	100-yr, 24 -hr storm (in)	10-yr, 24-hr storm vol (MG)	100-yr, 24-hr storm vol (MG)
Technical Paper 40	NOAA	1961	United States	3.5	4.8	6,691	9,176
Extreme Precipitation in New York and New England	NRCC-NRCS	2011	New York and New England	3.17	5.33	6,060	10,188
Atlas 14, Vol 10, Version 3.0	NOAA	2015	Northeastern States	3.48	5.32	6,653	10,169

* Rainfall over BSA service area of 110 sq mi.

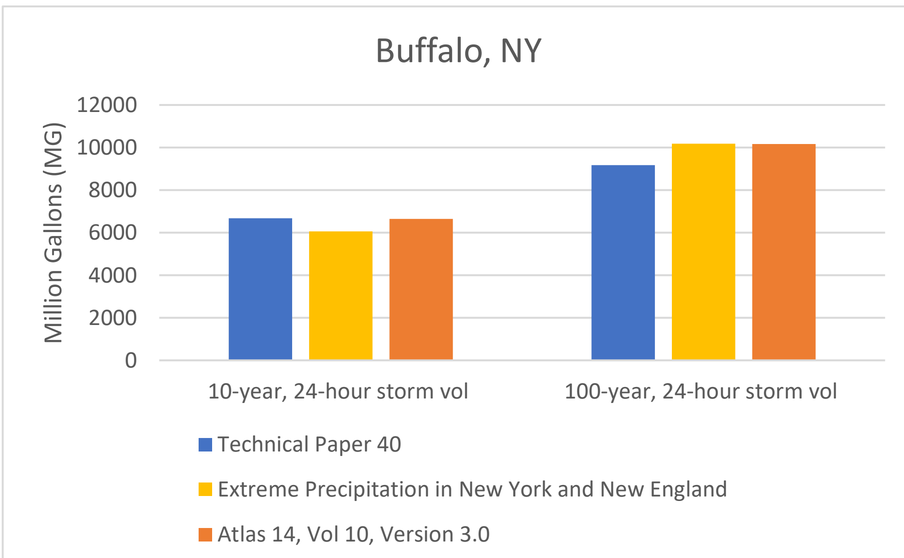

Figure 4. Changing Rainfall Estimates in Buffalo

As can be seen from Table 12 and Figure 4, between 2015 and 1961, Buffalo area 10-year rainfall amount has stayed steady. However, over the same time period, for the 100-year rainfall is higher by nearly 0.52 inches.

Table 13. Changing Rainfall Estimates in Chicago

Source	Agency	Publication Year	Study Spatial Extent	10-yr, 24-hr storm (in)	100-yr, 24-hr storm (in)	10-yr, 24-hr storm vol (MG)**	100-yr, 24-hr storm vol (MG)**
Technical Paper 40	NOAA	1961	United States	4.0	5.7	61,416	87,518
Bulletin 70*	ISWS	1989	Illinois	4.47	7.58	68,633	116,384
Atlas 14 Volume 2	NOAA	2006	US Ohio River Basin	4.29	6.95	65,689	106,711
Bulletin 75	ISWS	2020	Illinois	5.15	8.57	79,074	131,585

* Bulletin 70 and Bulletin 71 have identical PFEs for Illinois
** Rainfall over MWRDGC service area of 884 sq mi.

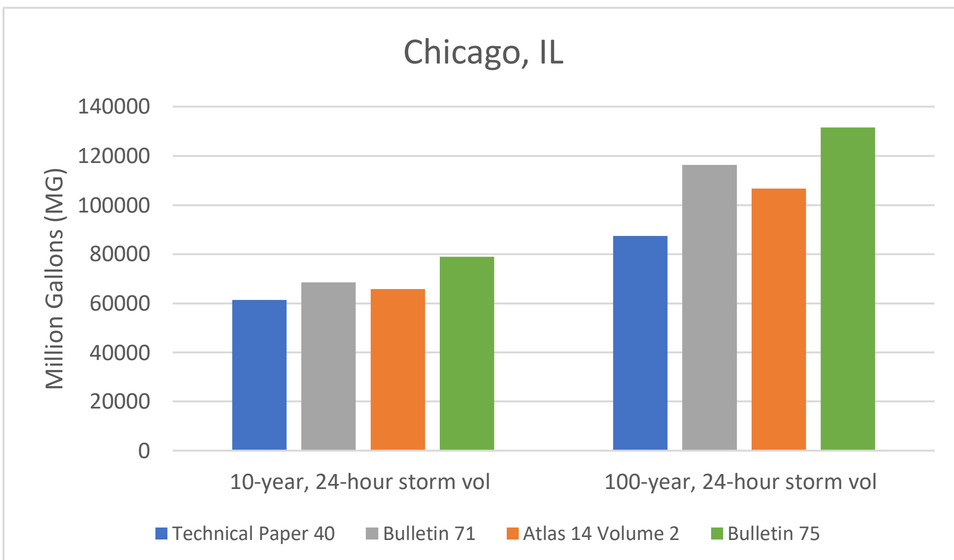

Figure 5. Changing Rainfall Estimates in Chicago

As can be seen from Table 13 and Figure 5, between 2020 and 1961, Chicago area 10-year rainfall amount has increased by 1.15 inches. And, over the same time period, for the 100-year rainfall is higher by nearly 2.9 inches and shows the largest increase over all other cities studied here-in.

Discussion
As discussed above, for the 10-year event, rainfall PFEs have stayed about the same or only slightly changed except in the Chicago area, where even the 10-year PFEs have increased by a significant amount.

For the 100-year event, however, the PFEs increased substantially at all locations. The minimum increase was 7% (Buffalo) and the maximum increase was Chicago, with a 50% increase over nearly six decades. Although runoff depths were not estimated, runoff depth increases would be even greater than the rainfall depth increases since the last inch of rainfall produces more runoff than the first inch of runoff for most land uses due to increasing saturation of the of the ground as the depth of rain increases.

6.0 Future Trends in Area Precipitation

Continued climate change impacts are expected to change PFE estimates across the region. For cities of Chicago, Detroit, and Buffalo, reports by agencies such as ISWS have developed detailed forecasts of changing rainfall. This chapter presents a summary of those existing reports.

CHICAGO, IL

A 2016 report published by the ISWS[14] , indicates that the Chicago metro region in northeastern Illinois is expected to face an increase in heavy rainfall events in the mid and late – 21st century. The report found that mid-century PFEs are expected to increase by 15% for both the 10-year and 100-year events, and the late century PFEs are expected to increase 20% for the same events. These percentage increases were applied to the currently used Bulletin 75 rainfall to estimate the mid- and late-century PFEs.

As can be seen in Figure 6, the 10-year event rainfall volume is expected to grow from 79,000 MG (2020, from 5.15 inches of rain) to 91,000 MG (2050, from 5.9 inches of rain) to 95,000 MG (2100, from 6.2 inches of rain). For the 100-year event, rainfall volume is expected to grow from 131,500 MG (2020, from 8.57 inches of rain) to 151,000 MG (2050, from 9.9 inches of rain) to 158,000 MG (2100, from 10.3 inches of rain).

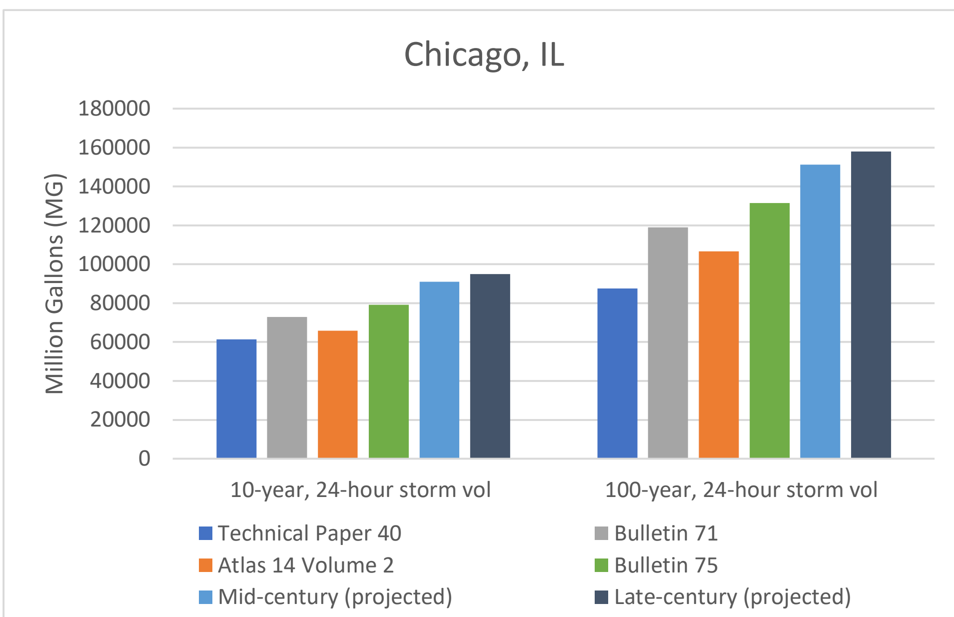

Figure 6. Chicago 10-yr and 100-yr Future Precipitation Estimates

[14] https://www.isws.illinois.edu/pubdoc/CR/ISWSCR2016-05.pdf

DETROIT, MI

For Detroit, the mid- and late-century numbers are based on a 2020 report published by *Southeast Michigan Council of Governments* and *Michigan Department of Transportation*[15].

As can be seen in Figure 7, the 10-year event rainfall volume is expected to grow from 8,000 MG (2013, from 3.31 inches of rain) to 13,000 MG (2050, from 5.5 inches of rain) to 19,000 MG (2100, from 7.9 inches of rain). For the 100-year event, rainfall volume is expected to grow from 12,445 MG (2013, from 5.13 inches of rain) to 15,000 MG (2050, from 6.1 inches of rain) to 24,500 MG (2100, from 10.1 inches of rain). These numbers are based on the average of the estimates for the two Detroit airports as published in the document referenced above.

The projected precipitation changes for the mid- and late-21st century are dramatic and suggest that the Detroit region will see much heavier rainfall than what is currently used for planning and design of infrastructure. In particular, the projected late-century 100-year rainfall volume is approximately double the currently used Atlas 14 volume.

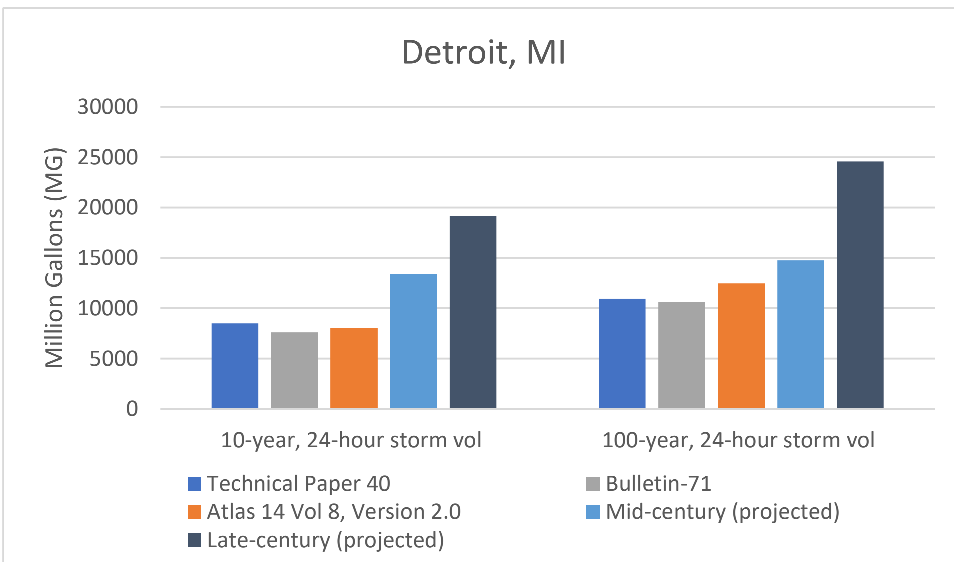

Figure 7. Detroit 10-yr and 100-yr Future Precipitation Estimates

BUFFALO, NY

In 2015, the Northeast Regional Climate Center published its findings of future projected changes (mid- and late-21st century) for a variety of storm sizes.[16]

As can be seen in Figure 8, the 10-year event, rainfall volume is expected to grow from 6,653 MG (2015, from 3.48 inches of rain) to 7,300 MG (2050, from 3.8 inches of rain) to 8,000 MG (2100, from

[15] https://semcog.org/Portals/0/Documents/Plans-For-The-Region/Environment/SE%20MI%20Current%20Future%20Precip%20June%202020.pdf?ver=UZcWge4Zq0G85YU7fAyr8g%3d%3d
[16] https://ny-idf-projections.nrcc.cornell.edu/index.html#dialog_box

6.5 inches of rain). For the 100-year event, rainfall volume is expected to grow from 10,169 MG (2015, from 5.32 inches of rain) to 12,000 MG (2050, from 4.2 inches of rain) to 13,000 MG (2100, from 7.0 inches of rain).

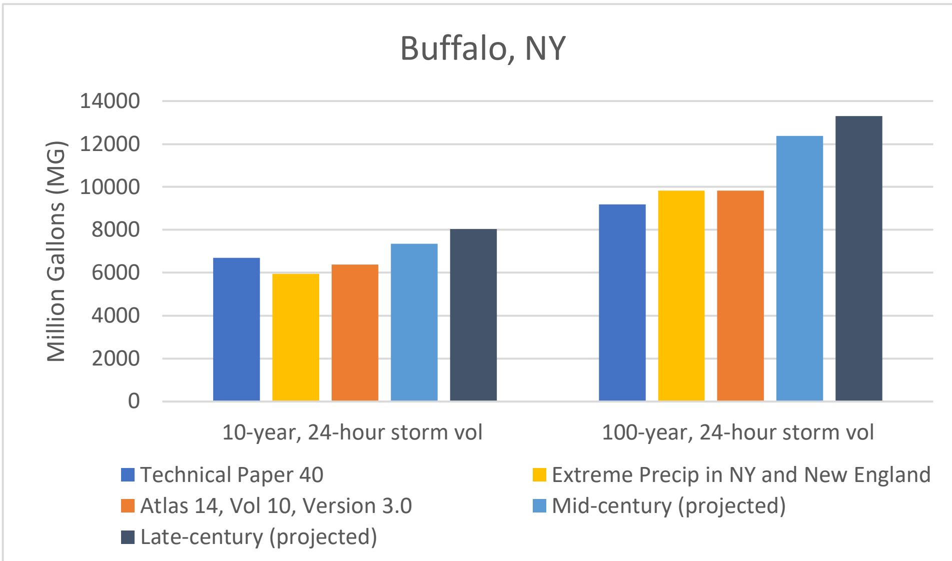

Figure 8. Buffalo 10-yr and 100-yr Future Estimates

These rainfall projections further underscore the need for communities to plan for a future in which existing infrastructure is insufficient and strategically expand investments to manage the increased volumes of stormwater in a sustainable and resilient manner.

7.0 Summary and Conclusion

The size and frequency of storm events is increasing and is expected to increase into the future. As a result, much of the infrastructure serving our major Great Lakes cities – that was designed and built decades ago – has insufficient capacity to meet original and current goals. To help system managers better evaluate potential capacity issues within their systems, changes in precipitation frequency estimates (PFE) were analyzed and reported in this document. As further documented in this report, the historical trend in PFE increases is expected to continue in the future given present trends in climate change. The following table presents precipitation amounts that were likely the basis of design for our current aging infrastructure, current design PFE, and projected future PFE at the mid-century and late century points.

Table 14. Summary of Historical, Current, and Projected PFE

	10-year, 24 hour PFE (inches)				100-year 24 hour PFE (inches)			
City	Historical	Current	Mid-century	Late-Century	Historical	Current	Mid-century	Late-Century
Milwaukee, WI	3.9	3.75	-	-	5.5	6.08	-	-
Detroit, MI	3.5	3.31	5.54	7.88	4.5	5.13	6.09	10.13
South Bend, IN	3.9	4.09	-	-	5.4	6.27	-	-
Chicago, IL	4	5.15	5.92	6.18	5.7	8.57	9.86	10.28
Buffalo, NY	3.5	3.48	3.84	4.2	4.8	5.32	6.48	6.96

Our analyses also found that in most locations, there is little change in the 10-year PFE from historical (1961) to current, except in Chicago region that shows a dramatically large change from the 1961 data. In all cases, the 100-year PFE increased, with increases varying from 11% more rain in Milwaukee to 50% increase in Chicago.

So far as future projects, for the mid- (and late-) century estimates, both the 10-year and 100-year PFE are expected to dramatically increase over the current values. For 10-year events:

- In Detroit: The rainfall amount is expected to increase by 67% by mid-century, and by 138% by the end of the century. These are massive changes.
- In Chicago: The rainfall amount is expected to increase by 15% by mid-century, and 20% by the end of the century.
- In Buffalo: The rainfall amount is expected to increase by 10% by mid-century, and 21% by the end of the century.

For 100-year events:

- In Detroit: The rainfall amount is expected to increase by over 19% by mid-century, and over 97% by the end of the century. These are massive changes.
- In Chicago: The rainfall amount is expected to increase by 15% by mid-century, and 20% by the end of the century.
- In Buffalo: The rainfall amount is expected to increase by 22% by mid-century, and 30% by the end of the century.

Overall, both regulatory agencies as well as municipal works leadership must use as current data as possible, and incorporate future climate related changes in clear focus so the systems designed and built today, continue to provide the intended level of service now and in the future.

Regulatory agencies and municipal works leadership also need to evaluate strategies to address currently undersized systems by scaling up the use of GSI across the region. Historically, this has been achieved through very large and centralized public works projects such as replacement and supplemental sewer interceptor sewers and large conveyance tunnels and storage reservoirs. While these systems can achieve many goals, they often do not address hyper-local capacity issues, and are very expensive and slow to design and install. GSI has the advantage of reducing the load on the current system, avoiding the need to replace or expand gray infrastructure while also addressing local capacity issues.

Finally, as documented in this report, the five wastewater agencies discussed here-in are in the process of installing significant volume of GSI. Driven at least partially by consent decree or permit mandates, that is a good trend and if EPA were to focus upon it further, the region stands to benefit accordingly.

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