Climate Resilience
Evaluation and Awareness
Tool Exercise Report

MANCHESTER-BY-THE-SEA, MASSACHUSETTS

July 6, 2015

EXECUTIVE SUMMARY

Manchester-by-the-Sea, Massachusetts provides drinking water and wastewater services to residents, tourists, and local businesses. The wastewater treatment plant (WWTP) is permitted to discharge up to 0.67 million gallons per day (MGD) as a monthly daily average for coastal resources protection, and is designed for 5 MGD of capacity for wet weather flow.

From November 2014 to June 2015, Manchester-by-the-Sea engaged in a series of webinars and an in-person meeting to conduct a climate risk assessment using the U.S. Environmental Protection Agency's (EPA) Climate Resilience Evaluation and Awareness Tool (CREAT). The risk assessment considered the impact of intense precipitation events and coastal storm surge in 2035 and sea level rise in 2060 on their WWTP. Manchester-by-the-Sea assessed their threats with warmer and wetter future conditions. With the implementation of potential adaptive measures, including constructing sea walls and asset relocation, Manchester-by-the-Sea found they could reduce all potential consequences of future coastal storm surge events and intense precipitation events to their headworks building from 'Very High' to 'Low', while the consequences from sea level rise itself in the 2060 time period were 'Low.' See **Table 1** for a summary of climate data that was used in the CREAT assessment.

Figure 1. *FEMA 100- and 500-year floodplain for area near Manchester-by-the-Sea*

.

Table 1: CREAT-Provided Data for Manchester-by-the-Sea

CLIMATE VARIABLE	HISTORICAL VALUES	CREAT PROJECTED VALUES (WARM AND WET MODEL PROJECTION	TIME PERIOD
Average Annual Temperature	48.92 degrees Fahrenheit	51.12 degrees Fahrenheit	2035
Total Annual Precipitation	47.05 inches	50.05 inches	2035
100-Year Storm	6.54 inches	6.91 inches	2035
Sea Level Rise	N/A	19.78 inches	2060

Manchester-by-the-Sea will continue to evaluate and compare the costs and benefits of constructing a sea wall on Manchester Harbor and implementing other adaptive measures to protect the WWTP, including relocating the WWTP to a new location on higher ground to avoid damage from coastal storm surge. While continuing to identify and reduce inflow and infiltration (I&I), the City has identified additional potential measures to control wet weather flows and bolster operations that reduce the risks associated with more frequent and intense rainfall events.

BACKGROUND

Manchester-by-the-Sea, Massachusetts provides drinking water and wastewater services to residents, tourists, and local businesses. This exercise focused on wastewater operations. The utility has three wastewater pump stations which are not expected to be threatened by storm surge. The WWTP is located at Manchester Harbor and is designed for an average daily flow of 1.2 MGD, a maximum daily flow of 3.0 MGD and an instantaneous maximum flow of 5.0 MGD. The WWTP is permitted to discharge a monthly average of 1.2 MGD from December through May and 0.67 MGD from June through November. It also has an Ocean Sanctuaries Act Limit of 0.67 MGD annual average for coastal resources protection. The WWTP has an 8,900 foot outfall that discharges outside the harbor at Misery Island.

The sanitary collection system serves about half of the community, but has a high rate of I&I during heavy precipitation events, therefore the WWTP was designed for a 5 MGD wet weather capacity. The WWTP is not permitted to bypass wastewater treatment, even during heavy flows. This capacity can become an issue in dry weather when the utility has difficulty pumping low flows through the treatment processes.

__Figure 2.__ Manchester-by-the-Sea WWTP

Increased influent flow and I&I issues during extreme precipitation events and facility inundation due to coastal storm surge/sea level rise are of concern. The utility has experienced a number of intense precipitation events in the past; during 2014, the area saw 7 inches of rain fall in a 24-hour period. The City is currently performing condition assessments to identify and eliminate

I&I, although budget constraints have restricted the amount of work which may be completed. The City is planning on spending $1M on I&I reduction over the next two years. The work will continue for a number of years to eventually reduce I&I with an affordable schedule.

Most of the WWTP is located within the 100- and 500-year FEMA floodplains. The headworks building is at a high risk of flooding because it is entirely in the floodplain, with entrances at grade. The headworks building houses non-submersible influent and effluent pumps below grade that would be inoperable if flood waters entered the structure. There are no sump pumps in the headworks building and the utility currently experiences seepage problems in the structure. Chemicals are also stored in the headworks building at grade, which is at risk of flooding. The parking lot adjacent to the WWTP has flooded during king tides and storm surges in the past and damaged meters and electrical conduits in service manholes. During extreme flooding events, the headworks building is at a primary risk of being flooded, which would leave the WWTP inoperable for some time. The WWTP has a backup generator that could provide power to the facility for about 10 days at 40% capacity.

Climate resiliency planning is being conducted for Manchester-by-the-Sea by Tighe & Bond, who have started to evaluate the potential impacts of storm surge and sea level rise on their infrastructure. Thus far, they have only completed coastal mapping using GIS showing what areas would be inundated with higher sea levels.

ASSESSMENT

Exercise Process

From November 2014 to June 2015, Manchester-by-the-Sea participated in a series of calls, webinars and one in-person event to guide them through a climate change risk assessment process. To better understand the vulnerability of their wastewater infrastructure and operations, Manchester-by-the-Sea assessed potential climate change impacts using the U.S. Environmental Protection Agency's (EPA) Climate Resilience Evaluation and Awareness Tool (CREAT)[1]. The assessment brought together individuals from various departments within Manchester-by-the-Sea, state agencies, local environmental organizations, and EPA Region 1 staff to think critically about potential climate impacts, priority assets and possible adaptation measures **(Appendix A)**. At the time of the assessment, Manchester-by-the-Sea was developing a Comprehensive Wastewater Management Plan, which would capture activities and plans for the next 20 years. Manchester-by-the-Sea is interested in using the results of the CREAT analysis to inform the development of the plan, as well as support grant or loan applications in the future to reduce the risk of flooding.

CREAT Analysis and Results

CREAT provides climate data within a risk assessment framework to help utilities understand climate change, assess risks, and evaluate adaptation measures. Leveraging the available information, several potential impacts of a changing climate were discussed including: higher wet weather flows at the WWTP due to increased precipitation, and WWTP flooding due to coastal storm surge and sea level rise. For assessment purposes, Manchester-by-the-Sea elected to focus on their critical asset at the WWTP, the headworks building. If the headworks building were to be inundated, the entire WWTP would be taken offline for an extended period of time.

Within CREAT, users can consider scenarios of projected changes in climate to assess consequences to their assets from climate-related threats. The three projected climate scenarios available in CREAT capture the range in potential future conditions at any given location within the US, based on Global Climate Model (GCM) calculations. While all models project warming, the anticipated changes in precipitation vary, with some forecasting wetter conditions and others

[1] EPA Climate Resilience Evaluation and Awareness Tool, available at: http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm

projecting drier conditions. Manchester-by-the-Sea used the CREAT-provided 'warm and wet' climate scenarios in their assessment (**Table 2**), focusing on the 2035 time period for the precipitation and flooding threats, and 2060 for the sea level rise threat. In the warm and wet scenario, total annual precipitation is projected to be 50.05 inches (6.39% increase) for 2035, and the 100-year storm is 6.91 inches of rain in a 24-hour period (5.77% increase) for 2035. A 'high' sea level rise curve was selected (1.5 meters of sea level rise by 2100), resulting in 19.78 inches of sea level rise in 2060. For more information on Manchester-by-the-Sea climate data, see **Appendix B**.

Table 2: Manchester-by-the-Sea Data Sources

CLIMATE PROJECTION	DATA
Warm/Wet Projected Climate Scenario	Warm/wet scenario in CREAT (Meteorological Institute Coupled Ocean-Atmosphere General Circulation Model, Meteorological Research Institute (Japan))
Sea Level Rise	High sea level rise curve (1.5 meters by 2100) 2035: 6.43 inches 2060: 19.78 inches

Manchester-by-the-Sea also reviewed data available in EPA's Storm Surge Inundation and Hurricane Frequency Map[2] to understand flooding threats and potential storm surge concerns. Selected threats were defined based on the available climate data, as shown in **Table 3**.

Table 3: Manchester-by-the-Sea Threat Definitions

THREAT NAME	THREAT DEFINITION	TIME PERIOD
Coastal Storm Surge	WWTP is inundated (king tides can reach 13.5 feet), additional 7 inches of sea level rise	2035
High Flow Events	Conditions similar to 2014 rain event of 7 inches of rain in a 24-hour period, occurring with increased frequency	2035
Sea Level Rise	20 inches of sea level rise, no storm surge considerations	2060

In general, risk assessments facilitate an evaluation of potential threats or hazards in terms of the likelihood of their occurrence and the consequences should they occur. Based on the likelihood that the rainfall, flooding and sea level rise threats will be realized during the selected time periods, Manchester-by-the-Sea elected to use the conditional likelihood setting within their CREAT analysis. This setting enabled them to consider the threat as occurring and to focus on how effective potential adaptation options would be at reducing consequences. The risk assessment framework in CREAT guides users through baseline and resilience analyses to gauge the potential future vulnerabilities of utility assets with and

[2] EPA Storm Surge Inundation and Hurricane Strike Frequency Map available at http://water.epa.gov/infrastructure/watersecurity/climate/stormsurge.cfm

without adaptation options. The baseline analysis includes current or existing actions only, while the resilience analysis includes additional potential adaptive actions.

To assess the level of consequence, CREAT provides a consequence matrix of five categories that capture the range of impacts a utility may experience. These include utility business impacts, utility equipment impacts, source and receiving water impacts, environmental impacts and community/public health impacts (**Appendix C**). Within each of these categories, Manchester-by-the-Sea assessed the impacts on a four-point qualitative scale from Low to Very High. CREAT combines these assessments to calculate an overall consequence risk level for each analysis.

Within their risk analysis, Manchester-by-the-Sea first performed a baseline assessment of the potential consequences of flooding from heavy precipitation events, flooding from coastal storm surges, and sea level rise to their infrastructure and operations given the adaptive measures currently employed. For the assessment of each of these potential threats, Manchester-by-the-Sea considered how the potential adaptive measures would help to lower consequence risks in a resilience analysis.

For coastal storm surge in 2035, Manchester-by-the-Sea compared the amount of consequence reduction and cost effectiveness of building a sea wall and several other potential measures as opposed to relocating the WWTP. Given the capabilities of the selected potential adaptive measures, Manchester-by-the-Sea was able to lower all potential consequences from ‘Very High’ to ‘Low’ for the flooding assessments. The sea wall and WWTP relocation would provide the same amount of consequence reduction, but cost and other external factors differ. See **Table 4** for the baseline and resilience assessment results. Baseline results illustrate the consequences the utility would expect to experience if the threat occurred, considering the utility’s current capabilities. Resilience results reflect new levels of consequences if the same threat occurred, but considering additional capabilities of potential adaptation options that could reduce consequences. Details on level definitions are provided in **Appendix C.**

Table 4. Manchester-by-the-Sea Baseline and Resilience Analysis Results for the Headworks Building/Coastal Storm Surge Assessment, Considering Either a Sea Wall or WWTP Relocation (2035 time period)

ANALYSIS	Utility Business Impacts	Utility Equipment Damages	Source/ Receiving Water Impacts	Environmental Impacts	Community/ Public Health Impacts
Baseline – Warm and wet model projection	LOW	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Resilience – Warm and wet model projection	LOW	LOW	MEDIUM	MEDIUM	MEDIUM

For high flow events in 2035, current condition assessment work is being performed to identify and reduce I&I, but that alone will not entirely address the potential threat to the WWTP equipment, operations, permit compliance, and surface waters uses should influent flows exceed the WWTP capacity. Potential adaptive measures were added to better control runoff, reduce I&I and protect the WWTP assets, which reduced the consequence level to ‘Low’. See **Table 5** for the baseline and resilience assessment results.

Table 5. Manchester-by-the-Sea Baseline and Resilience Analysis Results for the Headworks building/High flow events assessment (2035 time period)

ANALYSIS	Utility Business Impacts	Utility Equipment Damages	Source/ Receiving Water Impacts	Environmental Impacts	Community/ Public Health Impacts
Baseline – Warm and wet model projection	LOW	VERY HIGH	HIGH	HIGH	HIGH
Resilience – Warm and wet model projection	LOW	LOW	LOW	LOW	LOW

Even considering the high rate of sea level rise, the utility expected to experience a ‘Low’ level of consequences when considering current capabilities with the impacts of sea level rise and related wave action. Higher high tides and king tides would occur more frequently and flood the parking lot adjacent to the WWTP. With the anticipated wave action and projected sea level rise, sea water may flood service manholes and enter the headworks building, resulting in some short-term damage to pumps and electrical controls. Several potential adaptation measures are expected to reduce consequences from this impact. See **Table 6** for the baseline and resilience assessment results.

Table 6. Manchester-by-the-Sea Baseline and Resilience Analysis Results for the Headworks building/Sea level rise assessment (2060 time period)

ANALYSIS	Utility Business Impacts	Utility Equipment Damages	Source/ Receiving Water Impacts	Environmental Impacts	Community/ Public Health Impacts
Baseline – Warm and wet model projection	LOW	MEDIUM	LOW	LOW	LOW
Resilience – Warm and wet model projection	LOW	LOW	LOW	LOW	LOW

NEXT STEPS

Based on the results of the analysis of the storm surge threat, Manchester-by-the-Sea is comparing the costs and benefits of constructing a sea wall on Manchester Harbor to protect the WWTP, or relocating the WWTP to a new location on higher ground to avoid damage from coastal storm surge. More data is needed to determine the height of the sea wall needed to protect the WWTP, but the utility was encouraged to use the 100-year flood level plus 2 feet of freeboard, with an additional safety factor incorporated to account for projected sea level rise.

Manchester-by-the-Sea will also expand current I&I reduction measures, increase community outreach, and join the mutual aid network, Massachusetts Water/Wastewater Agency Response Network (MAWARN)[3].

[3] More information on MAWARN available at http://www.mawarn.org/.

APPENDIX A: EXERCISE PARTICIPANTS

NAME	CONTACT INFORMATION	AFFILIATION
Greg Federspiel	federspielg@manchester.ma.us	Manchester-by-the-Sea, MA
Carol Murray	murrayc@manchester.ma.us	Manchester-by-the-Sea, MA
Mary Reilly	reillym@manchester.ma.us	Manchester-by-the-Sea, MA
John Sibbalds	sibbaldsj@manchester.ma.us	Manchester-by-the-Sea, MA
Barbara Warren	barbara.warren@salemsound.org	Salem Sound Mass bays Program
Kristin Divris	kristin.divris@state.ma.us	Massachusetts Department of Environmental Protection
Curt Baranowski	Baranowski.curt@epa.gov	EPA Headquarters
Jane Downing	Downing.Jane@epa.gov	EPA Region 1
Lynn Gilleland	Gilleland.Lynn@epa.gov	EPA Region 1
Regina Lyons	Lyons.Regina@epa.gov	EPA Region 1
Gina Snyder	Snyder.Gina@epa.gov	EPA Region 1
Ivy Milsna	Milsna.Ivy@epa.gov	EPA Region 1 Fellow
Laura Dubin	Dubin.laura@epa.gov	EPA ORISE
Mike Maier	Maier.michael@epa.gov	EPA ORISE
Bill McMillin	McMillin.William@CH2M.com	CH2M
Susan Butler	Butler.Susan@CH2M.com	CH2M
Steve Fries	jfries3@csc.com	CSC
Amy Posner	aposner@csc.com	CSC
Ashley Stevenson	abrosius@csc.com	CSC
Elise Tao	jtao2@csc.com	CSC

APPENDIX B: CLIMATE DATA

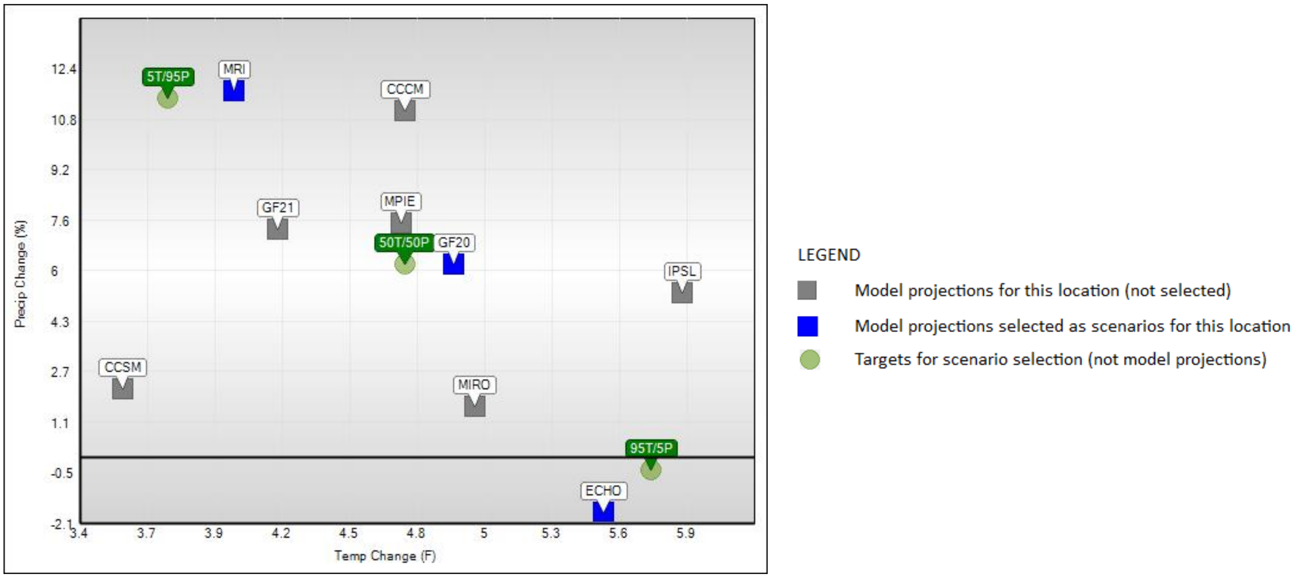
Climate Model Selection for Manchester-by-the-Sea

The scatter plot of model run results below provides a visual of how the CREAT-provided scenarios were selected. Each point represents the projected changes in average annual temperature and total annual precipitation in 2060 for the ½ degree cell containing Manchester-by-the-Sea, Massachusetts. For each scenario, the selected model was used to generate monthly changes in average conditions as well as the changes in intense precipitation event magnitudes on annual and seasonal bases.

Model projections for changes in average annual conditions for the 2060 time period were considered to evaluate the distribution of possible future conditions and to select three models that best describe the range of projections. This selection was based on finding the specific model that projected a change in conditions nearest to three statistical targets, each indicative of certain projected changes. The three scenarios provided in CREAT are called:

- **Hot and dry model projection** – model nearest the 5th percentile of precipitation and 95th percentile of temperature projections (larger increase in temperature with lower total precipitation)
- **Central model projection** – model nearest the 50th percentile of both precipitation and temperature projections (central condition, among models, for temperature and total precipitation)
- **Warm and wet model projection** – model nearest the 95th percentile of precipitation and 5th percentile of temperature projections (smaller increase in temperature with larger total precipitation)

The terms dry and wet are used here relative to the range of total precipitation projected for this location in 2060 time period. For example, dry does not always indicate a reduction in total precipitation relative to today; dry simply indicates projected total precipitation on the lower end of distribution of projected precipitation. A horizontal line on the plot indicates no projected change in precipitation (i.e., 0%) to help distinguish those models projecting increases in annual total precipitation from those projecting decreases.



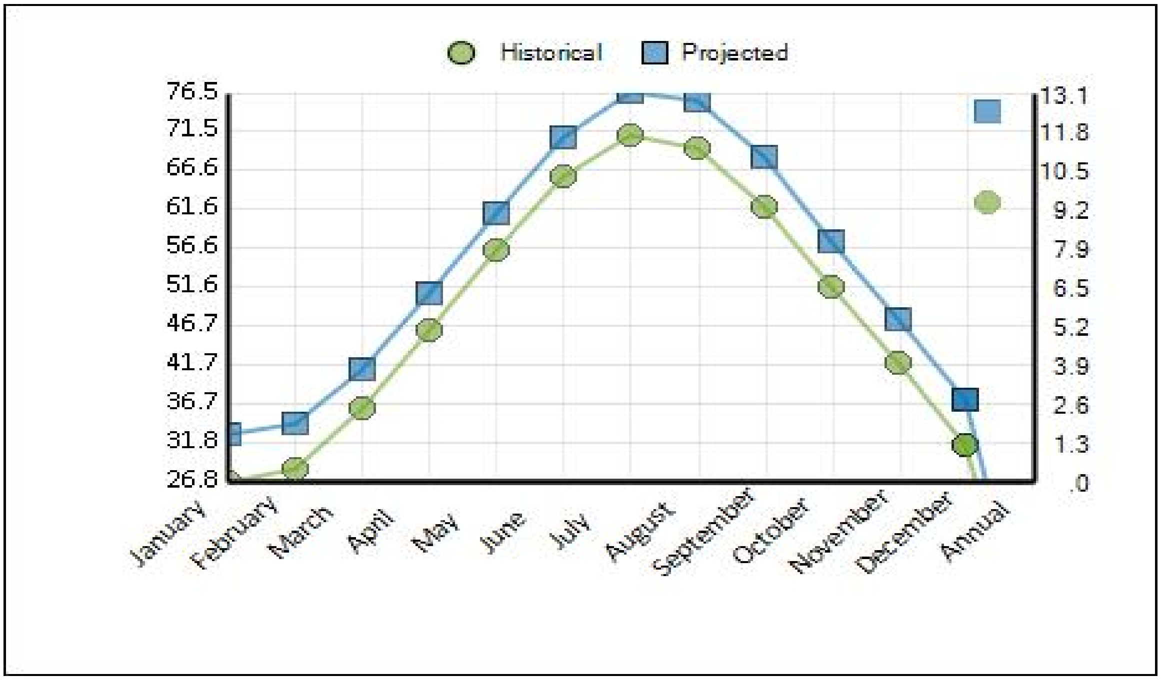
Warm and Wet Model Projection: Projected Climate Conditions for the Year 2035 in Manchester-by-the-Sea, Massachusetts

AVERAGE TEMPERATURE DATA (°F)		TOTAL PRECIPITATION DATA (INCHES)	
ANNUAL	51.12	ANNUAL	50.05
JAN	29.88	JAN	4.97
FEB	30.78	FEB	3.76
MAR	38.26	MAR	4.46
APR	47.97	APR	4.45
MAY	58.73	MAY	3.66
JUN	68.00	JUN	3.49
JUL	72.90	JUL	3.47
AUG	71.60	AUG	3.45
SEP	63.82	SEP	4.34
OCT	53.65	OCT	4.34
NOV	44.08	NOV	5.23
DEC	33.62	DEC	4.42

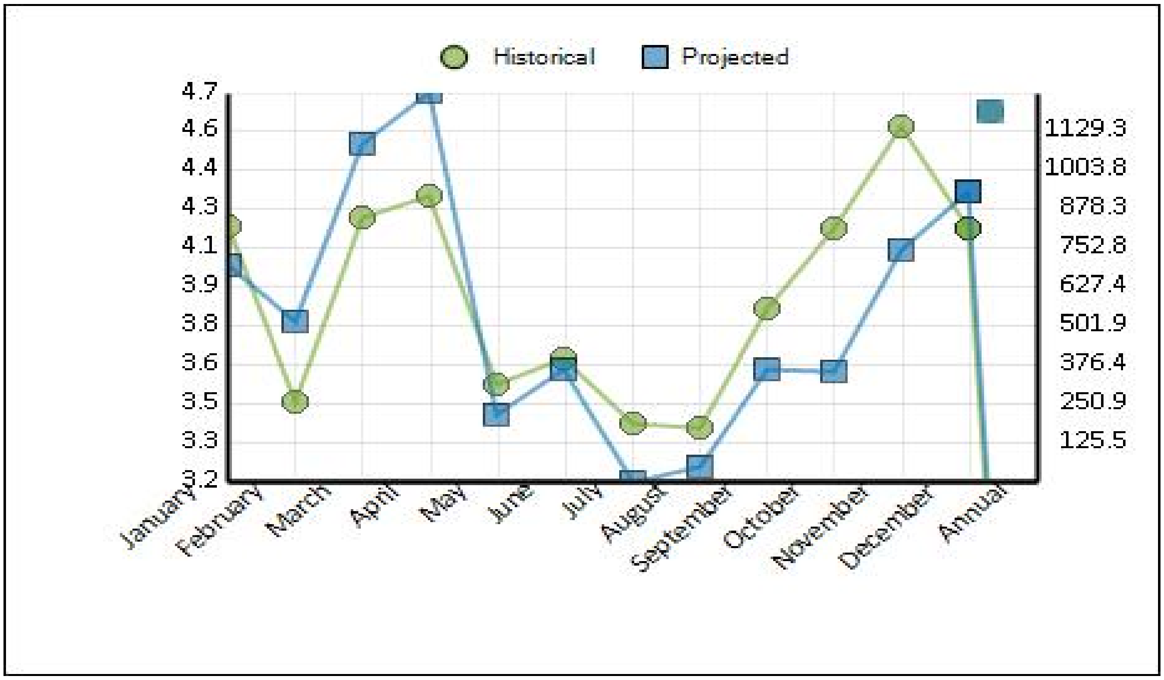
Total Precipitation (inches) During 24-Hour Event

RETURN INTERVAL	ANNUAL	WINTER (DJF)	SPRING (MAM)	SUMMER (JJA)	FALL (SON)
5-YEAR	3.71	2.50	2.50	2.46	3.13
10-YEAR	4.37	2.91	3.04	2.95	3.74
15-YEAR	4.78	3.16	3.33	3.24	4.11
30-YEAR	5.49	3.53	3.86	3.78	4.82
50-YEAR	6.07	3.83	4.24	4.20	5.36
100-YEAR	6.91	4.21	4.83	4.75	6.16

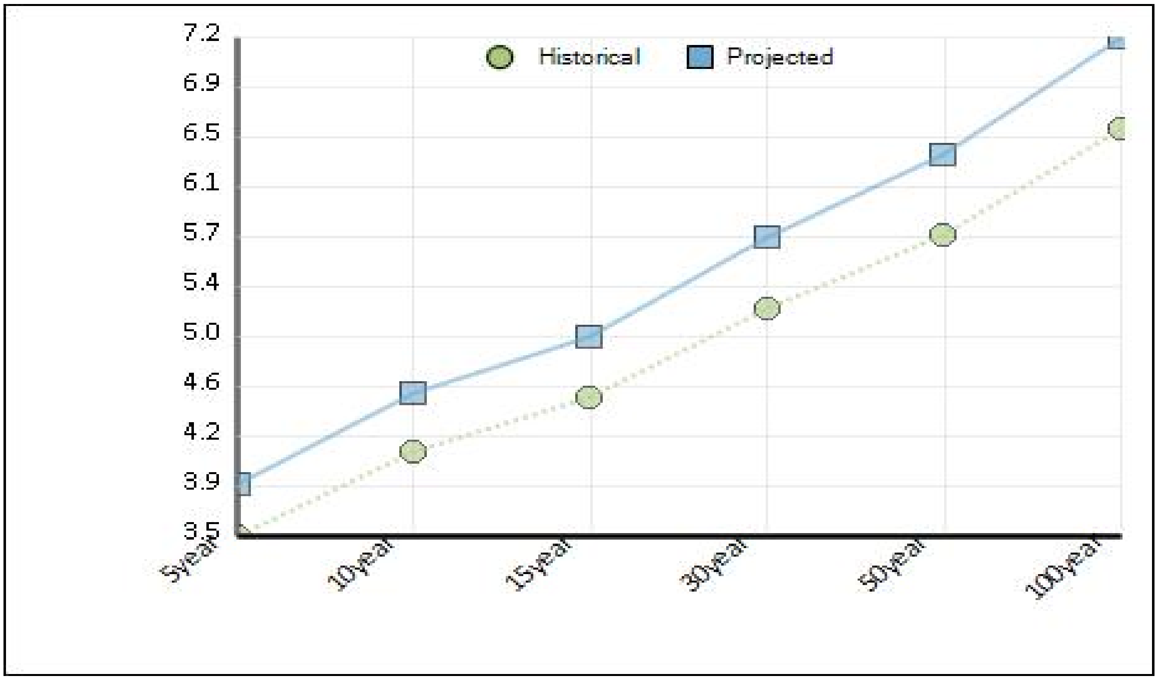
Average Temperature



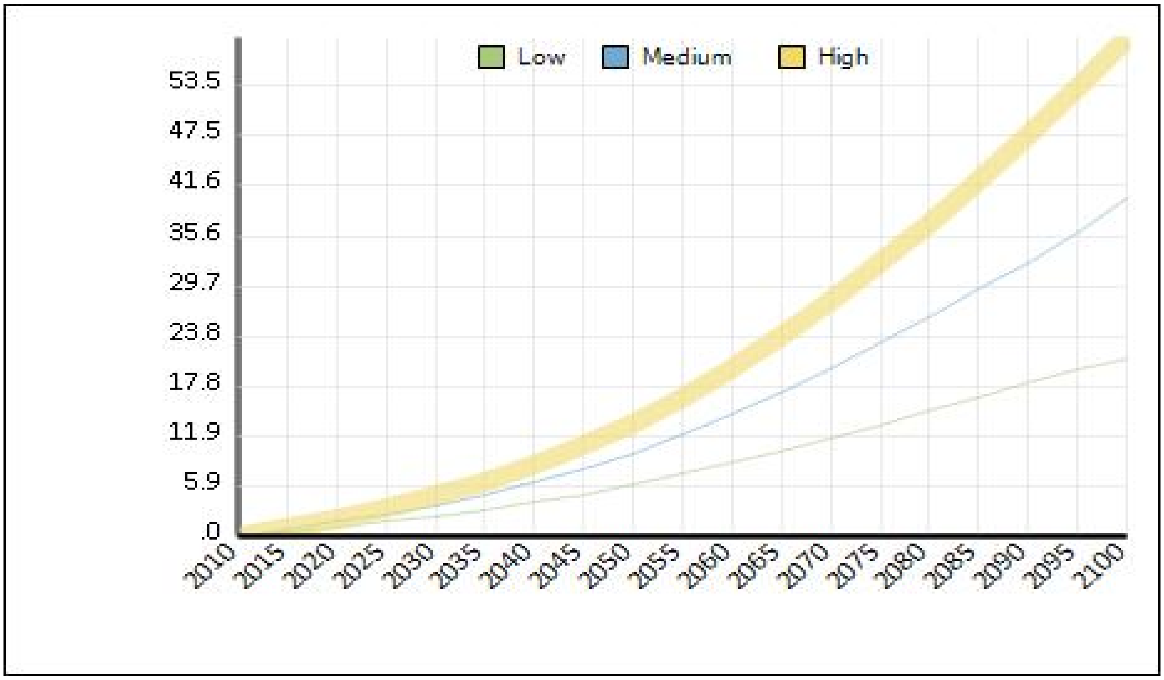
Total Precipitation



24-h Event Precipitation for 2060



Sea Level Rise



APPENDIX C : CONSEQUENCE CATEGORIES AND LEVEL DESCRIPTIONS

Title	Utility Business Impacts	Utility Equipment Damage	Source/ Receiving Water Impacts	Environmental Impacts	Community Public Health Impacts
Description	Revenue or operating income loss evaluated in terms of magnitude and recurrence of service interruptions	Costs of replacing the service equivalent provided by a utility or piece of equipment evaluated in terms of magnitude of damage (minimal, minor, significant, complete loss) and financial impacts (flexible cost scale, “$x,” can be customized by each user)	Degradation or loss of source water or receiving water quality and/or quantity, evaluated in terms of recurrence (minimal, temporary, seasonal or episodic, long-term)	Evaluated in terms of environmental damage or loss (aside from source water or other assets) and compliance with environmental regulations (minimal, short term, persistent/permit violations significant impact and/or regulatory enforcement and actions)	Evaluated in terms of duration (short- or long-term) and extent (minimal, minor, localized, or widespread)
Very High	Long-term and/or significant loss of expected revenue or operating income	Complete loss of asset; replacement costs of $x++	Long-term compromise of source water quality and/or quantity	Significant environmental damage — may incur regulatory action	Long-term and/or widespread public health impacts
High	Seasonal or episodic – but minor – compromise of expected revenue or operating income	Significant damage to equipment; costs estimated at <$x+	Seasonal or episodic compromise of source water quality and/or quantity	Persistent environmental damage – may incur regulatory action	Short-term and localized public health impacts
Medium	Minor and short-term reductions in expected revenue or operating income	Minor damage to equipment; costs estimated at <$x	Temporary impact on source water quality and/or quantity	Short-term environmental damage, compliance can be quickly restored	Minor public health impacts
Low	Minimal potential for any attributable loss of revenue or operating income	Minimal damage to equipment	No more than minimal changes to source water quality and/or quantity	No impact or environmental damage	No impact on public health
Weight	20	20	20	20	20