Assessing the Vulnerability of Combined Sewer Systems to Sea Level Rise

A Case Study in the New York-New Jersey Harbor Estuary

EPA United States Environmental Protection Agency
HUDSON RIVER FOUNDATION
NY/NJ HARBOR & ESTUARY PROGRAM

Table of Contents

Executive Summary

Past and projected sea level rise make it critical to better understand the vulnerability of the Region's many combined sewer outfalls. In partnership with EPA and two combined sewer system communities in New Jersey, the New York-New Jersey Harbor & Estuary Program (HEP) piloted EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) to look at the potential impacts of sea level rise on combined sewer overflows (CSOs), specifically looking at a subset of utility infrastructure – outfalls. Recognizing that New Jersey began to advance the development of Long Term Control Plans (LTCPs), an opportunity arose to engage two CSO municipalities to pilot CREAT.

CREAT is an online decision support tool designed for drinking water and wastewater utilities to evaluate operational and infrastructure changes to build long-term resilience. The tool provides climate projection data within a risk assessment framework to help assist drinking water, wastewater and stormwater utility owners and operators in understanding and addressing climate change risks. The framework contains five modules to help users conduct a risk assessment to evaluate potential adaptation options for implementation. At the end of a CREAT assessment, users can compare the estimated monetized risk reduction obtained by implementing adaptive measures against the cost of implementing those measures. The assessment includes quantified consequences as well as current and potential adaptive measures across a range of climate scenarios. The results of a CREAT assessment provide information that systems and municipalities can use to inform future investments and long-term planning.

The City of Elizabeth and the Village of Ridgefield Park utilized CREAT as a sensitivity analysis to look at several scenarios. Both municipalities considered a "more wet and stormy" condition with moderate sea level rise. To help evaluate the effectiveness of the tool, Ridgefield Park selected to consider a worst case "More Wet and Stormy with High Sea Level Rise" while Elizabeth selected a best case "Wet and Stormy with Low Sea Level Rise" as a second scenario. By examining information on the two CSO outfalls in Elizabeth and Ridgefield Park and supplemental customized data against these future scenarios, the CREAT tool showed the potential monetized risk reduction benefits of the two adaptation plans. While the costs of implementing the two adaptation plans significantly exceed the potential monetized risk reduction, it is important to note that the adaptive measures considered to reduce the impacts of sea level rise were primarily developed to address CSO control objectives. Any monetized risk reduction realized through implementing the suggested adaptive measures should therefore be seen as an added co-benefit beyond the intended CSO control outcomes.

The pilot project concluded with both municipalities having an improved understanding of CREAT and insight into how a variety of climate factors can be considered in a cost-benefit analysis in conjunction with the development of a LTCP. CREAT assessments could be used to supplement analyses for implementation of LTCP alternatives as they relate to future climate conditions. CREAT also offers guidance in how it presents the potential consequences and relative benefits for a suite of prospective adaptation measures. The visual representations and formatted reports provided by the tool could support public engagement around integration of climate change considerations into the LTCP process. CREAT can provide useful information for LTCPs that go beyond just CSO control measures and add the benefit of flood mitigation and sea level rise.

Sea Level Rise Vulnerability in the Harbor Estuary

Global sea level is rising, with projections of 0.9 to 1.8 feet by the 2050s and a worst-case projection of up to six feet by 2100 (IPCC, 2014; NPCC, 2015). The New York-New Jersey Harbor Estuary is projected to rise between 0.9 and 2.1 feet by 2050, a rate faster than the global average (Kopp et al., 2019). Increased precipitation and high intensity storms will lead to greater volumes of polluted stormwater directly entering the estuary. These greater volumes will likely increase the number and volume of discharges when combined stormwater and sewage inflows exceeding the capacity of sewage treatment plants are diverted to receiving waters (Van Abs, 2016). High tides and sea levels can flood catch basins, flood communities, and combined sewer communities will have a greater likelihood of producing overflows on a tidal schedule.

With many of New Jersey's combined sewer outfalls already underwater during higher tidal periods, a further analysis of sea level rise impacts is needed to evaluate the vulnerability of the combined sewer systems, specifically the outfalls (JWW, 2019). The state of New Jersey has 21 municipalities with active combined sewer systems, 17 of which are found within the Harbor Estuary. In 2015, the New Jersey Department of Environmental Protection issued new combined sewer overflow (CSO) permits requiring each CSO municipality to develop a Long Term Control Plan (LTCP) by 2020. As part of the LTCP, New Jersey permit holders evaluated the last 70 years of precipitation data to identify 2004 as the average design year (typical year) to run hydrologic models and evaluate the CSO systems. The 2004 design year was identified to consider climate change and the increased precipitation events in the state and inform the LTCP's *Development and Evaluation of Alternatives Report* (DEAR) and the Selection and Implementation of Alternatives Report. While the typical hydrologic year used to evaluate CSO control alternatives was selected to be a conservative representation of annual precipitation over a broad historical period, the LTCP requirements do not explicitly require permittees to assess impacts associated with sea level rise and future conditions outside of historical weather observations.

Improving and sharing information on climate change and sea level rise impacts to water quality is an action identified by the New York-New Jersey Harbor & Estuary Program (HEP) and its partners in the 2017-2025 Action Agenda as well as HEP's climate vulnerability assessment (Pirani, et al, 2018; see WQ-E-1; Pirani & Boicourt, 2018). To expand the range of climate change impacts considered, HEP collaborated with the U.S. Environmental Protection Agency (EPA) and two New Jersey municipalities, the City of Elizabeth and the Village of Ridgefield Park, to pilot an assessment on the risks of impacts from sea level rise to CSO outfalls. Over the course of 2019-2020, project partners were engaged in piloting the Climate Resilience Evaluation and Awareness Tool (CREAT) and other resources from EPA's Creating Resilient Water Utilities (CRWU). Partners aimed to identify the best use of the tool for systems where ownership from a treatment plant to the outfall does not fall under one entity, and evaluate how environmental conditions, like sea level rise, and extreme weather events could affect sewer infrastructure (e.g., CSO outfalls).

Climate Resilience Evaluation and Awareness Tool (CREAT)

Developed by EPA's CRWU initiative, CREAT[1] is an online decision support tool to evaluate operational and infrastructure changes that can help build long-term resilience. It provides climate projection data within a risk assessment framework to help assist drinking water, wastewater and stormwater utility

[1] EPA Climate Resilience Evaluation and Awareness Tool, available at: https://creat.epa.gov.

owners and operators in understanding and addressing climate change risks. The framework contains five modules, building on one another, to help users conduct a risk assessment to evaluate potential adaptation options for implementation. These modules include:

- Climate Awareness (entering utility information and potential threats),
- Scenario Development (selecting potential climate scenarios and reviewing climate data),
- Consequences and Assets (defining the scale and definitions of damage categories),
- Adaptation Planning (identifying existing and potential adaptive measures to address each threat), and
- Risk Assessment (comparing annual monetized risk reduction of adaptation plans across scenarios for all considered assets and threats).

The tool allows for both historical climate data and future climate scenarios by utilizing data available from national public databases built into CREAT or a custom user-provided data set. It is important to note that CREAT provides a data-informed risk assessment framework; it is not a model (e.g., hydrologic, or hydraulic model), although model outputs can be input into the tool to reflect localized climate threats and adaptive measures to inform capital planning and decision-making.

Working with EPA, HEP engaged the City of Elizabeth and the Village of Ridgefield Park to pilot CREAT in the evaluation of potential impacts of sea level rise to CSO outfalls in the region. HEP provided two small grants to the City of Elizabeth and the Village of Ridgefield Park to participate in a hands-on opportunity with EPA as a case study representing two different sized communities and challenges within the state of New Jersey. As captured in Figure 1, the CREAT exercise process launched in the summer of 2019 with preliminary discussions followed by a kickoff call in September. Following an initial webinar to introduce CREAT, the CREAT team participated in an onsite visit in October to observe outfalls in the Village of Ridgefield Park and the City of Elizabeth and conduct CREAT working sessions. A second webinar was held in November to confirm and adjust assessment assumptions and review the exercise results.

Figure 1. *CREAT Process for the City of Elizabeth and the Village of Ridgefield Park*

The project culminated with a HEP-sponsored regional workshop for New Jersey CSO permit holders and partners – state officials, municipal engineers, planners, utility operators, and their consultants – to discuss the climate-related threats in the region and examine the economic losses associated with sea level rise at CSO outfall locations. Representatives from Elizabeth and Ridgefield Park shared how they used CREAT to think critically about their potential climate impacts, possible adaptation options, and monetized risk reduction plans. The following sections of this report highlight both Elizabeth and Ridgefield Park's experience using CREAT. Partners also conducted a regional webinar to inform stakeholders about how climate-related threats can be best addressed during the implementation of LTCPs and future permit conditions.

Case Study: City of Elizabeth and the Village of Ridgefield Park

Both Elizabeth and Ridgefield Park conducted a high-level CREAT risk assessment of their combined sewer system, with a focus on one CSO outfall and its prospective impacts of sea level rise on street and residential flooding in each community.

The City of Elizabeth focused on CSO Outfall 035A (Figure 2) which sits in a low-lying area adjacent to the Elizabeth River and is tidally influenced. When wet weather events and high tides coincide, localized flooding within the outfall's drainage area occurs. The outfall outlet is equipped with a duckbill-style check valve, or tide gate, to prevent backflow. The bottom of the duckbill check valve is close to the riverbed, and periodic maintenance is required to address accumulated sediment. Sea level rise is expected to increase the backpressure condition on the outfall pipe, increasing the likelihood of street and residential flooding. Damage from flooding includes property damage to houses and cars, hindered traffic flows, and contamination requiring cleanup after floodwaters have subsided. While excess flows from CSO outfall 035A can be diverted through a relief outfall (043A) to a pump station and levee system, during Superstorm Sandy in 2012 the system was nearly overtopped.

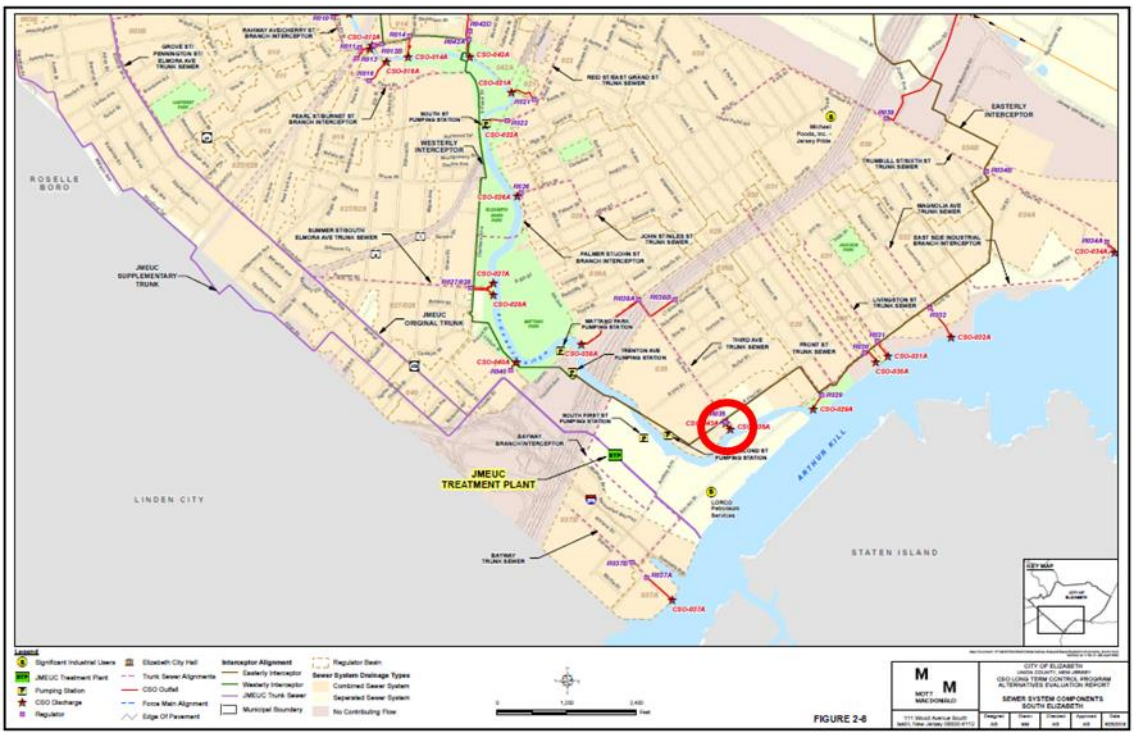

***Figure 2**. City of Elizabeth Location Map, DEAR June 2019 CSO Long Term Control Plan NJPDES #: NJ0108782*

The Village of Ridgefield Park focused on CSO Outfall 001A (Figure 3) located in a low-lying area adjacent to the Hackensack River which is tidally influenced. Sea level has been rising in this area, increasing the extent to which the outfall remains submerged throughout the tidal cycle. While a flap-type tide gate prevents backflow into the system, high tides can restrict the discharge of wet weather flows. When the drainage area for the outfall floods, portions of a main road and its neighboring side streets can become submerged. This flooding hinders traffic flow, and the police or Department of Public Works (DPW) may be needed to detour through-traffic.

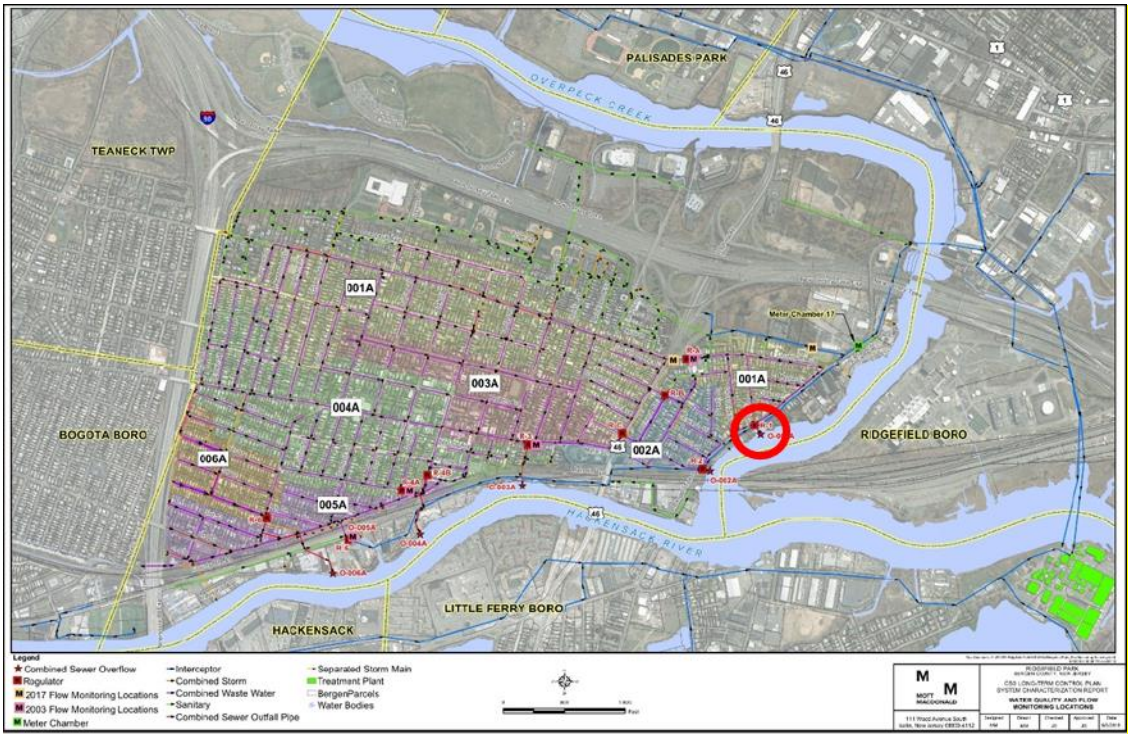

***Figure 3**. Ridgefield Park Location Map, DEAR July 2019 CSO Long Term Control Plan NJPDES #: NJ0109118*

Defining Threats and Assets in CREAT

The first step in CREAT is to include information about each outfall. This includes the population being served by each CSO outfall, an approximate address, and the estimated millions of gallons per day (MGD). For the purposes of this case study, Elizabeth and Ridgefield Park's CSO outfalls serve a population of 3,000 to 5,000 (per the system's hydraulic model) and an estimated volume of 0.3 and 0.5 MGD.[2] Sea level rise was identified as the main threat to the CSO outfalls, with a focus on flooding. The increased intensity of precipitation events combined with sea level rise will increase the likelihood of outfalls to be submerged more often and result in backflows and street flooding. Using historic climate baseline data from the National Oceanic and Atmospheric Administration (NOAA) National Weather Service data (NOAA, 2017)[3], both municipalities identified 2050 as a planning horizon to align CREAT outputs with the projected LTCP planning horizon. For the purposes of this case study, both Elizabeth and Ridgefield Park chose a "more wet and stormy" future scenario, including a sea level rise option, and a second scenario for sensitivity.

The first scenario, "More Wet and Stormy with Moderate Sea Level Rise," was defined as a future with moderate sea level rise and high levels of increased total annual precipitation as well as increased rainfall during intense precipitation events. For both municipalities, this estimated a roughly 16% increase of precipitation during 2-,5-, and 10-year intense precipitation events. The second scenario the municipalities decided on had slightly different projections to understand sensitivity through a worst-case and best-case scenario. Ridgefield Park selected a "More Wet and Stormy with High Sea Level Rise," defined as a future with high sea level rise and high levels of increased total annual precipitation, as well

[2] Dry weather flow was drawn from modelled data provided by Elizabeth and Ridgefield Park's consultants Mott MacDonald.

[3] For the purposes of this case study, the default projection values provided by CREAT to capture change in annual temperature, precipitation, and increase in intensity of intense precipitation events were utilized. Please see CREAT 3.0 Methodology Guide (2016) for additional details on the model datasets used for this assessment. https://www.epa.gov/sites/production/files/2016-05/documents/creat_3_0_methodology_guide_may_2016.pdf

as increased rainfall during intense precipitation events (a worst-case scenario). Elizabeth selected a "Wet and Stormy with Low Sea Level Rise," defined as a future with low sea level rise and very low levels of increased total annual precipitation, as well as lower increases in rainfall during intense precipitation events (a best-case scenario). Projected climate scenarios were selected based on the New Jersey Climate Adaptation Alliance Advisory Committee Science and Technical Advisory Panel Report's Central Estimate for 2050 (i.e., 50% probability), while the high sea level rise scenario uses the 1-in-200 chance estimate for 2050 (i.e., 0.5% probability) (Kopp et al., 2016; See Table 1 and 2).

Table 1. Values for Elizabeth Baseline and Projected Climate Scenarios

	Baseline Scenario	More Wet & Stormy w/ Moderate Sea Level Rise	Wet & Stormy w/ Low Sea Level Rise
2-Year Intense Precipitation Event	3.3 in/24-hr	16.05% increase	1.00% increase
5-year Intense Precipitation Event	4.05 in/24-hr	15.99% increase	1.38% increase
10-year Intense Precipitation Event	4.71 in/24-hr	16.16% increase	0.61% increase
Sea Level Rise By 2050 (Inches)	N/A	17.3 in	12.37 in

Table 2. Values for Ridgefield Park Baseline and Projected Climate Scenarios

	Baseline Scenario	More Wet & Stormy w/ Moderate Sea Level Rise	More Wet & Stormy w/ High Sea Level Rise
2-Year Intense Precipitation Event	3.3 in/24-hr	16.06% increase	16.06% increase
5-year Intense Precipitation Event	3.67 in/24-hr	15.99% increase	15.99% increase
10-year Intense Precipitation Event	4.3 in/24-hr	16.16% increase	16.16% increase
Sea Level Rise By 2050 (Inches)	N/A	17.3 in	27.14 in

The next step includes building the economic consequences matrix within CREAT. CREAT presents the option to choose between default consequence categories or the creation of custom consequence categories. These categories may include some or all the following impacts: utility business, equipment damage, environmental, and source/receiving water. Both Ridgefield Park and City of Elizabeth chose to only monetize two custom categories – Street Flooding Remediation and Residential Flooding – with cost categories based on internal discussions (i.e., boundary limits from low to high risk). Street Flooding Remediation was defined as costs associated with staff time and equipment needed in response to an event (e.g., closing streets) and the subsequent clean-up (e.g., cleaning catch basins), while Residential Flooding was defined as structural damage and property loss, including vehicles, after a flood event. Table 3 presents how higher consequence levels and increasing costs are associated with more frequent flooding and/or flooding of greater spatial extent. The ability to utilize default consequences or customize consequences is one of the most valuable features of CREAT. The tool enables the user to generate a sensitivity analysis to look at respective results across the spectrum. However, the lack of real data underlying many of the assumptions made through the tool as part of this case study confirms that there is a clear need for future data collection and modeling for more precise results.

Table 3. Economic Consequences Matrix (Estimated Annual)[4]

Levels	**Street Flooding Remediation**	**Residential Flooding**
Very High	*Frequent and significant remediation across wide spatial scale*	*11+ residences / events*
	$7,000 - $15,000+	$110,000+
High	*Frequent remediation or significant remediation*	*6-10 residences / events*
	$3,000 - $15,000	$50,000 - $100,000
Medium	*Moderate remediation across wide spatial scale (multiple streets)*	*2-5 residences / events*
	$1,000 - $6,000	$20,000 - $50,000
Low	*Minimal remediation for highly localized flooding (single intersection / single event)*	*Minimal residential impact (1 residence)*
	$0 - $1,000	$0 - $10,000

Planning and Assessing Results in CREAT

The next phase in CREAT is the Adaptation Planning module that provides a platform for discussion of the potential adaptive measures that can be taken. Existing adaptive measures are also entered, and for this case study, the City of Elizabeth implemented a duckbill backflow prevention on the outfall along with sewer pipe and pump station upgrades, while Ridgefield Park had a flap-type tide gate to prevent backflow. Drawing from potential adaptive measures outlined in the LTCP, such as satellite storage tanks, green infrastructure, and end-of-the-pipe treatment, CREAT can help assess the degree to which considered CSO control options could help reduce impacts from sea level rise.

Finally, in the Risk Assessment module, the user begins to pair the asset and threat together. For each identified asset the user identified the impact category (low, medium, high, or very high) that matches each adaptation plan and future scenario. The results allow comparison of adaptation costs with risk reductions to determine which adaptive measures are justifiable for each asset. The module also includes a likelihood sensitivity step, where the user can consider how different scenario likelihoods may impact support or counter a decision to adapt, where lower likelihood of some scenarios would effectively reduce the projected risk reductions.

For the projected climate scenarios, the costs of implementing the two adaptation plans by Elizabeth and Ridgefield Park significantly exceed the full range of potential monetized risk reduction. However, the potential adaptive measures have been developed to address CSO control objectives, rather than to reduce sea level rise impacts. Any monetized risk reduction realized through implementing these adaptive measures should therefore be seen as an added benefit beyond the intended CSO control outcomes for both the City of Elizabeth and Village of Ridgefield Park (see Figure 4 and 5).

[4] The estimate on residential flooding is from the 2018 report, "The Growing Threat of Urban Flooding: A National Challenge" (pg. 28). This publicly available study can be found here: https://cdr.umd.edu/urban-flooding-report.

		Baseline Scenario	More Wet & Stormy with Moderate Sea Level Rise	Wet & Stormy with Low Sea Level Rise
Current Measures	Street Flooding Remediation	Medium	High	Medium
	Property Flooding	Low	High	Medium
Satellite Storage Tank	Street Flooding Remediation	Low	Medium	Low
	Property Flooding	Low	Medium	Low
Tank + Green Infrastructure	Street Flooding Remediation	Low	Medium	Low
	Property Flooding	Low	Medium	Low

Figure 4. *Illustrative monetized risk reduction for Elizabeth: Storage tank under a More Wet & Stormy with Moderate Sea Level Rise future.*

		Baseline Scenario	More Wet & Stormy with Moderate Sea Level Rise	More Wet & Stormy with High Sea Level Rise
Current Measures	Street Flooding Remediation	Medium	High	Very High
	Property Flooding	Low	Medium	High
Satellite Storage Tank	Street Flooding Remediation	Low	Medium	Medium
	Property Flooding	Low	Low	Low
End-of-Pipe Treatment	Street Flooding Remediation	Low	Medium	Medium
	Property Flooding	Low	Low	Low

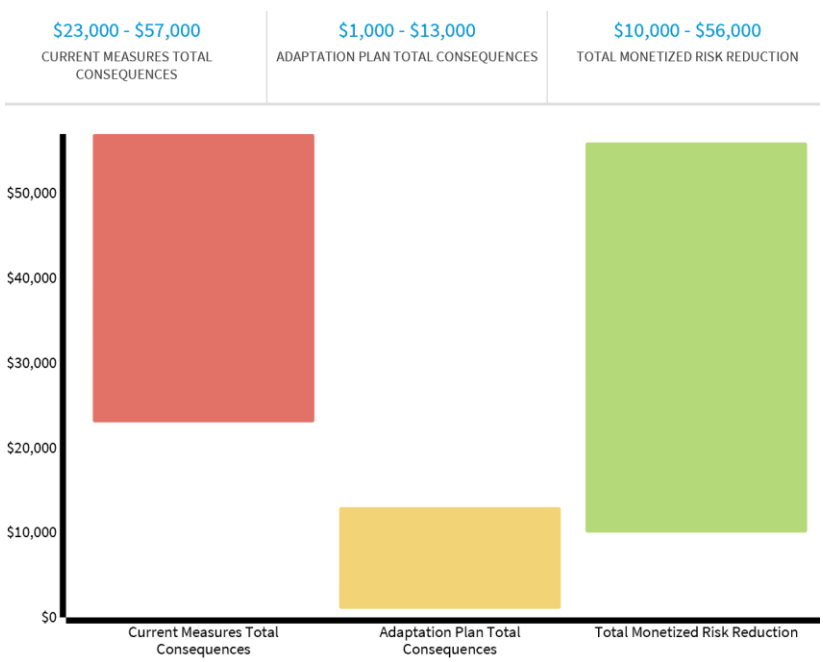

Figure 5. *Illustrative monetized risk reduction for Ridgefield Park: Storage tank under a More Wet & Stormy with Moderate Sea Level Rise future.*

CREAT provided a valuable sensitivity analysis for investigating different extreme weather and sea level rise scenarios and identifying and quantifying their potential impacts. The development of custom consequence categories based on the potential for street and/or residential flooding enabled Elizabeth and Ridgefield Park to develop an assessment more applicable to CSOs. In doing so, both New Jersey municipalities gained insight into the additional analyses and information that would be useful to obtain or model for future assessments. For example, CSOs are more impacted by peak storm intensities, so inputting precipitation events with shorter time intervals into CREAT (e.g., 15-minute or 1-hour precipitation data) would be more relevant than the 24-hour and 72-hour precipitation events currently

captured in CREAT. Additional hydrological model runs for the conditions in the assessed scenarios would also inform future use of CREAT to refine results even further. Similarly, there is a wide range in the costs and benefits of adaptive measures depending on the severity of the selected scenario and how the costs and benefits of controls are enumerated. Information more directly related to the economic impacts of street flooding or sea level rise would allow for more concrete assessment results.

Future Considerations and Lessons Learned

Using the results of their CREAT assessments, Elizabeth and Ridgefield Park were able to evaluate the costs of several potential flood management strategies that, if implemented, could further strengthen the operational resilience of their systems. Ridgefield Park found CREAT to be a powerful tool to think about climate impacts on projects, organizing project data, assessing project impacts, and then cleanly presenting and comparing the direct and secondary benefits of implementing mitigation efforts. They noted that CREAT's built-in data could generate concept costs for treatment based on population served or dry weather flows, although it was not applicable in their case. The City of Elizabeth had a similar experience with the tool as Ridgefield Park. The assumptions made over the course of the exercise also helped them identify the types of data they would want to develop, refine, and use in future assessments for a more precise risk assessment output. These outputs could potentially be used as tools for future public engagement.

CREAT's library of data was identified as a valuable resource in addition to the tool's ability to customize data from ongoing modeling efforts help make CREAT's projections more specific to the local issues and evaluate secondary benefits such as social and economic risk reductions. However, it was cautioned that some pre-set items in CREAT were not directly applicable to CSOs (i.e., 15-minute or 1-hour precipitation data), therefore requiring customized inputs. CREAT is most powerful when integrated with data derived from long-term modeling and use from historical threat events (such as resident damage claims). Both municipalities suggested that if threat-related consequences could be monetized, CREAT could also be used to evaluate the impacts and damages, extending the municipality's understanding of impacts to flood events such as required emergency responses and equipment costs. The case study also suggested that improving resilience to flooding was a clear additional benefit of implementing the LTCP measures considered by both municipalities. CREAT could thus be used to quantify the additional risk reduction from flooding that the City of Elizabeth and Ridgefield Park could gain from implementing LCTP measures.

A valuable sensitivity analysis for investigating extreme weather and sea level rise scenarios and identifying and quantifying their potential impacts, CREAT is a useful tool for CSO communities. CREAT assessments could be used to supplement analyses for LTCP implementation as they relate to future climate conditions. The visual representations and formatted reports provided by the tool could support public engagement around integration of climate change considerations into the LTCP process. These documents can act as living documents and may be updated in the future as the utility's understanding of their threats, assets, and adaptive measures changes. As sea level continues to rise, it is important that the communities begin to use sea level rise models to identify the timing and level of sea level rise impacts on combined sewer systems and take preventative action to mitigate tidally associated CSO.

References

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

Jersey Water Works (JWW). 2019. *Hidden Capacity: A Report on How Proper Maintenance and Cleaning of Sewer Systems can have Huge Benefits.* Jersey Water Works Combined Sewer Overflow Committee. Trenton, NJ.

New York City Panel on Climate Change (NPCC). 2015. *New York City Panel on Climate Change 2015 Report*. Annals of the New York Academy of Sciences. 1336: 1-150.

Pirani, R and Boicourt, K., 2018. *Climate Change: And its Impact on the NY-NJ Harbor & Estuary Program*. Hudson River Foundation. New York, NY.

Pirani, R; Stinnette, I; Da Silva, R; Lerman-Sinkoff, S; Lodge, J; Giudicelli, A; and Boicourt, K., 2018. NY–NJ Harbor & Estuary Program Action Agenda 2017-2022, Hudson River Foundation. New York, NY.

Van Abs, D.J. 2016. *Climate change adaptation in the water supply sector*. Prepared for the Rutgers New Jersey Climate Adaptation Alliance.

Jersey Water Works (JWW). 2019. *Hidden Capacity: A Report on How Proper Maintenance and Cleaning of Sewer Systems can have Huge Benefits.* Jersey Water Works Combined Sewer Overflow Committee. Trenton, NJ.

Kopp, R.E., C. Andrews, A. Broccoli, A. Garner, D. Kreeger, R. Leichenko, N. Lin, C. Little, J.A. Miller, J.K. Miller, K.G. Miller, R. Moss, P. Orton, A. Parris, D. Robinson, W. Sweet, J. Walker, C.P. Weaver, K. White, M. Campo, M. Kaplan, J. Herb, and L. Auermuller. 2019. New Jersey's Rising Seas and Changing Coastal Storms: Report of the 2019 Science and Technical Advisory Panel. Rutgers, The State University of New Jersey. Prepared for the New Jersey Department of Environmental Protection. Trenton, New Jersey.

Kopp, R.E., A. Broccoli, B. Horton, D. Kreeger, R. Leichenko, J.A. Miller, J.K. Miller, P. Orton, A. Parris, D. Robinson, C.P.Weaver, M. Campo, M. Kaplan, M. Buchanan, J. Herb, L. Auermuller and C. Andrews. 2016. *Assessing New Jersey's Exposure to Sea-Level Rise and Coastal Storms: Report of the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel.* Prepared for the New Jersey Climate Adaptation Alliance. New Brunswick, New Jersey.

National Oceanic and Atmospheric Administration National Weather Service. 2017. *NOAA Atlas 14 Point Precipitation Frequency Estimates: NJ*. Retrieved October 22, 2019, from https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nj.

Van Abs, D.J. 2016. *Climate change adaptation in the water supply sector*. Prepared for the Rutgers New Jersey Climate Adaptation Alliance

Suggested Citation

Pedra Nobre, R., Fries, S., Baroang, K., Hall, A. (2022). Assessing the Vulnerability of Combined Sewer Systems to Sea Level Rise: New Jersey Case Studies using EPA's Climate Resilience Evaluation and Awareness Tool (CREAT). Hudson River Foundation. New York, NY.

Disclaimer