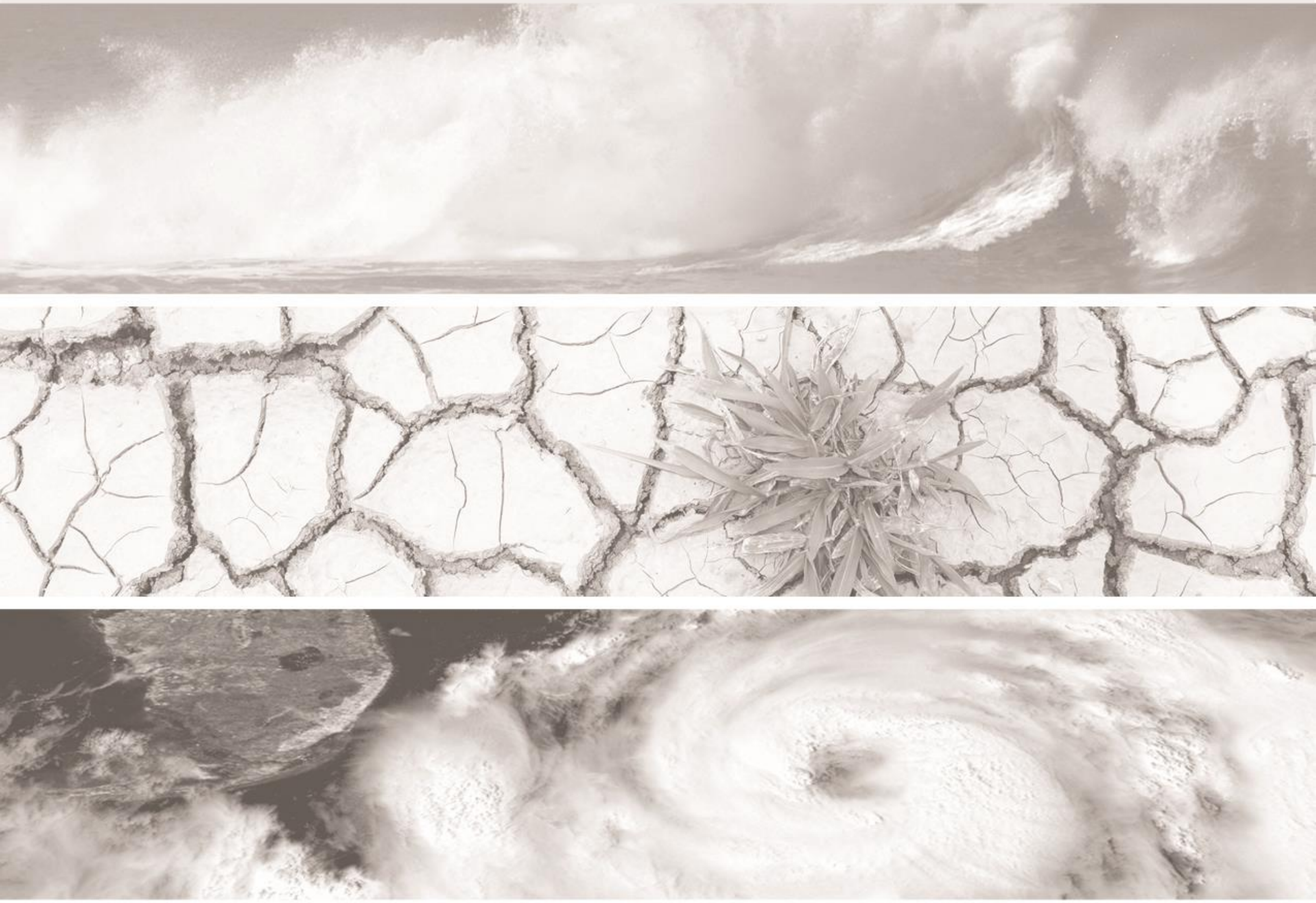
United States Environmental Protection Agency

CLIMATE RESILIENCE EVALUATION AND AWARENESS TOOL (CREAT) EXERCISE REPORT

MANCHESTER-BY-THE-SEA



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MANCHESTER-BY-THE-SEA, MASSACHUSETTS

January 2023

EXECUTIVE SUMMARY

Manchester-by-the-Sea (MBTS) is a coastal Eastern Massachusetts water system that provides drinking water services to approximately 5,400 residents via 37 miles of public water mains. The system has two water sources: the Lincoln Street Well and aquifer; and Gravelly Pond and the adjacent Round Pond, from which water is transferred to supplement natural recharge, and its associated water treatment plant (WTP). MBTS provides an average of approximately 0.7 million gallons of water per day (MGD), with summer rates averaging 1 MGD. Gravelly Pond is used most heavily in the summer season, when demand is highest. During the winter, the Lincoln Street Well is used more heavily to allow water levels in Gravelly Pond to recover from the summertime drawdown.

From February through August 2022, representatives from MBTS, the U.S. Environmental Protection Agency (EPA) Creating Resilient Water Utilities Initiative (CRWU), the National Oceanic and Atmospheric Administration (NOAA), and the Massachusetts Department of Environment (Mass DEP) participated in a series of working sessions to conduct a climate change risk and resilience assessment. Using the EPA Climate Resilience Evaluation and Awareness Tool[1] (CREAT), MBTS assessed its drinking water system to better understand the vulnerabilities of their utility infrastructure and operations to climate stressors. The CREAT assessment brought together individuals to think critically about potential climate impacts, prioritize assets, consider possible adaptation options, and compare monetized risk reduction across Adaptation Plans. MBTS had previously worked with EPA in 2015 to conduct a CREAT assessment of the impact of flooding from heavy precipitation events, coastal storm surge, and sea level rise on its wastewater infrastructure and operations.

This CREAT assessment focused on two climate threats: 1) drought, and a resulting decrease in the quantity of available source water, and 2) saltwater intrusion into groundwater from sea level rise, and a resulting degradation of source water quality at the Lincoln Street well. The threats were explored under both historical baseline climate conditions as well as under a “Hotter and Drier” scenario 30 years in the future (2052). Through the exercise, MBTS considered how various climate factors could influence its ability to meet drinking water demand fully and efficiently. The priority assets identified for this exercise were MBTS’ two sources of drinking water, Gravelly Pond and the associated Round Pond Well and water treatment plant (WTP), and the Lincoln Street Well and its associated aquifer.

To assess the potential impact climate change could have on these assets, monetary values were assigned to levels of economic consequences. MBTS chose to consider and monetize the following economic consequences categories: *Utility Business Impacts* to account for a possible decrease in revenue; *Utility Equipment Damage* to account for infrastructure damage and related expenses; *Environmental Impacts* to account for environmental damage or loss, aside from water resources, and the cost of compliance related to environmental regulations; and *Source/Receiving Water Impacts* to account for degradation of source water quality or loss of quantity, evaluated in terms of recurrence. MBTS used custom quantified estimates for each of the consequences categories. MBTS also chose to consider and monetize Regional Economic Consequences, which captures the economic impacts of water system service disruption or reduction on the wider community.

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

Using CREAT, MBTS assessed and monetized potential consequences from drought and saltwater intrusion across climate scenarios. The team assessed potential impacts were drought or saltwater intrusion to occur, and how these impacts might change if they were to implement resiliency measures. Three Potential Adaptation Plans were evaluated for their ability to reduce the impact of drought and saltwater intrusion and improve MBTS's capacity to respond to or recover from climate change impacts. In addition to assessing a Current Measures Plan (status quo operations and assets), MBTS assessed the following three Adaptation Plans: 1) Develop and Utilize Interconnections (with the Town of Beverly), 2) Develop a New Well, and 3) Increase Watershed Protection through land acquisition and/or expansion of the source water protection overlay. There was not great specificity in the size, location, or alternative land uses of properties that might be involved in the third strategy. The MBTS team estimated the cost to implement each Adaptation Plan, allowing the team to calculate the monetized risk reduction for each threat under a Baseline Scenario and a Hotter and Drier Future Scenario.

The assessment results suggest that implementing any of the potential Adaptation Plans could provide some financial benefits from climate risk reduction for the Lincoln Street Well even if 2052 conditions remain similar to the Baseline Scenario (historic conditions). There is some uncertainty about the extent of benefit given the costs of implementation and the minimal financial risk posed by drought and saltwater intrusion under historic conditions.

Under future conditions of high heat, reduced summertime precipitation, and high sea level rise, both Gravelly Pond and the Lincoln Street Well and associated aquifer would be exposed to significant threat, and the monetized risk to MBTS and the surrounding community is considerable. Drought could deplete both surface water and groundwater sources, potentially leading to reductions in service for all users and increased pumping and treatment costs. Saltwater intrusion into the Lincoln Street well could require installation of a costly treatment system or, if significant enough, abandonment of the well, which would leave MBTS dependent solely upon Gravelly Pond for all its water. This would overtax Gravelly Pond, hinder its ability to recharge during the winter, and make it more vulnerable to drought. MBTS would very likely be unable to provide enough water to meet current demand under this type of scenario.

Under a Hotter and Drier Future Scenario in which MBTS's assets are depleted or rendered unusable due to drought or water quality degradation, the system faces high levels of risk. The annualized monetized risk to the utility was calculated by CREAT by threat type (Drought and Water Quality Degradation) and by asset (the Lincoln Street Well/Aquifer and Gravelly Pond/WTP). Regional economic impacts resulting from reduced service were similarly calculated. Given MBTS's current measures, CREAT calculated a series of risk results that can be found in **Table 6-7**. Two of the Adaptation Plans identified by MBTS could offset risks significantly: utilizing interconnections with Beverly and acquiring a new well. These adaptations could allow for MBTS to overcome the loss of one or both of their assets. For example, the associated risk reductions for both plans when analyzing the threat of drought on the Lincoln Street Well were calculated by CREAT as each exceeding $176,673 for the utility. These Adaptation Plans were also shown by CREAT to substantially reduce the economic impacts that would be borne by the community served by MBTS. This regional risk was calculated by CREAT at $372 million, and these two Adaptation Plans were shown to reduce this by $279 million (Interconnections) and $346 million (New Well). The benefits of these plans would allow MBTS to avoid critical reductions in service in a worst-case scenario. The third Adaptation Plan considered, investing in watershed protection, has much more modest potential to minimize economic impacts of drought or saltwater intrusion, although there may be other benefits.

This assessment is preliminary and is intended to provide a basis for further evaluation. Assumptions about costs, the ability of neighboring communities to sell water, and the quality and productivity of potential new wells could be refined to further guide decisionmakers. MBTS may also wish to consider the potential for adaptive measures to provide other benefits to the water system or the broader community that were outside the scope of this assessment.

BACKGROUND

Utility Overview

MBTS is a water system located on coastal Cape Ann in Essex County, Massachusetts. It provides drinking water services to approximately 5,400 residents and has 37 miles of public water mains. MBTS operates and maintains a WTP and distribution system providing approximately 0.7 MGD on average, with summer rates averaging 1 MGD. Most of this seasonal increase is attributed to outdoor landscape irrigation. MBTS sources its water from Gravelly Pond and the Lincoln Street Well.

MBTS is currently undertaking a planning initiative for protecting critical water resources. The Select Board of the Town commissioned a Water Resource Protection Task Force in late 2021, with the goal of establishing a long-term vision for maintaining water quality and quantity and providing recommendations to the Town. Some members of the Task Force, participated in the CREAT assessment, and there was overlap on issues touched upon in this assessment, including the threats from drought and water quality degradation.

System Overview

MBTS has two main water sources: Gravelly Pond and the Lincoln Street Well. Gravelly Pond is a surface water source that supplies approximately 60% of the Town's water on an annual basis. Gravelly Pond, and the Town's water treatment facility at Gravelly Pond, are located northwest of the Town's border in the neighboring Town of Hamilton, MA. The maximum water level in Gravelly Pond is 31 feet, and summer draw down routinely lowers levels below 25 feet, sometimes low enough that intakes are affected. Gravelly Pond is part of a system of small ponds. A well, located on the shore of the adjacent Round Pond, transfers raw water directly to Gravelly Pond. The water is then chlorinated to oxidize iron and manganese and settling occurs in an adjacent lagoon. Gravelly Pond's intake is located opposite the side of the settling lagoon, and transfers water to the Town's water treatment facility. MBTS owns the ponds and portions of the surrounding land and watershed. The hydrogeology of the ponds is not known for certain: no streams feed into Gravelly Pond, and the direct catchment area is relatively small; it is believed that it may be fed in part by groundwater. There are two closed and capped landfills nearby, but there is currently no evidence of contamination.

MBTS's second source is the Lincoln Street Well, which draws groundwater from an aquifer. The Lincoln Street Well produces approximately 40% of the Town's water annually, and pumps directly into the distribution system after treatment. During the winter season, the Town uses the Well as the primary water source to enable recharge of Gravelly Pond. The hydrogeology of the aquifer is not precisely known, but it is suspected that it is influenced, at least in part, by the nearby Sawmill Brook which runs to the harbor and is tidally influenced. While there is an old dam that separates the Brook from the harbor, it is expected to be removed, after which the Brook will be directly connected with the harbor.

MBTS must transport water from Gravelly Pond through an aging distribution system that suffers from leaks, and much of the infrastructure is 100+ years old. MBTS is in the process of replacing older mains and spends about $1 million annually on replacements, particularly along the coastal areas where soil salinity has eroded the pipes. The Lincoln Street Well generally has very good water quality, but does have high concentrations of iron and manganese, and varying ranges of sodium levels (which are thought to be attributable to wintertime road salt). MBTS uses zinc polyphosphate to sequester the iron and manganese, sodium chloride for disinfection, sodium hydroxide for pH adjustment, and sodium fluoride for fluoridation.

ASSESSMENT

Exercise Process

Following the success of the 2015 CREAT evaluation of climate risks and adaptive measures for their wastewater system, MBTS focused on the drinking water supply for their 2022 assessment. From February through September 2022, representatives from MBTS, EPA Region 1, EPA CRWU, NOAA, and Mass DEP participated in a series of working sessions to conduct a climate change risk and resilience assessment and evaluation of several adaptive measures to decrease the consequences of climate change threats (see **Appendix A** for a list of participants). MBTS used CREAT to better understand the vulnerability of utility infrastructure and operations. The CREAT assessment allowed MBTS to think critically about potential climate impacts, prioritize assets, consider possible adaptation options, and compare monetized risk reduction across plans and climate scenarios.

CREAT provides climate projection data within a risk assessment framework to help utilities understand climate change, assess risks from climate-related threats, and evaluate potential adaptation options for implementation. Within CREAT, users assess consequences from climate-related threats that can impact utility assets and operations and assess the benefits of implementing adaptation options to protect those assets and operations. At the end of a CREAT assessment, users can explore monetary values that compare the risk reduction obtained by implementing Adaptation Plans against the cost of implementing those adaptive measures. As a decision support tool, CREAT also enables users to evaluate the likelihood of climate change scenarios occurring and how that can affect the cost-effectiveness of adaptation options. Other benefits from adaptation can be considered, including energy usage and socio-economic impact (benefit or cost). The results of a CREAT assessment provide information that utilities can use to inform future investments and long-term planning.

CREAT Assessment

Several potential impacts from climate change were discussed. To start the CREAT process, MBTS identified a range of current concerns:

- **Water Supply Management** – Gravelly Pond is vulnerable to drought, and the Lincoln Street Well may be as well. This vulnerability, coupled with increased demand during summer months, may make it difficult to meet water demands especially in a hotter, drier climate scenario.
- **Peak Service Challenges** – Seasonal demand increases may put additional stresses on the system, especially during a hotter, drier climate scenario.
- **Water Quality Degradation** – The aquifer that the Lincoln Street Well draws from may be vulnerable to saltwater intrusion. The surface water source at Gravelly Pond has levels of iron and manganese that have been known to occasionally increase substantially after periods of heavy or extended precipitation, when there are drastic water quality changes from the Round Pond Well and Round Pond Well settling lagoon, and during turnover in Gravelly Pond due to seasonal stratification. PFAS has not been detected above the current maximum contaminant level in either the aquifer or the well, but the Town is aware that the system may be vulnerable to PFAS contamination.
- **Natural Disasters** – The Town is vulnerable to floods and ice storms.
- **Interdependent Sector Reliability** – MBTS is interdependent with other sectors, and this could cause reliability problems related to power access and treatment chemicals.
- **Sea Level Rise** – The Town is located directly on the coast, with the downtown very likely to be impacted by even modest sea level rise.

For the CREAT assessment, MBTS chose to focus on two specific threats: **Drought** and **Water Quality Degradation**.

MBTS chose to assess these threats using a **30-year timescale** (i.e., 2022 – 2052). With technical assistance from EPA, MassDEP, and NOAA, MBTS used CREAT to develop a better understanding of the resilience of their assets to projected changes in climate for that period. Once determined, the team worked to assess the performance of different mitigation strategies under a projected climate change scenario.

Historical and Projected Climate Information

CREAT provides data for historical and projected climate conditions. Users can incorporate this data into different scenarios to help them understand how threats are driven by climate change. Users build scenarios by selecting different future conditions defined by changes in various climate metrics, including the following:

- Average annual or monthly temperature,
- Average annual or monthly precipitation,
- Severity of intense precipitation events,
- Average annual surface water flows, and/or
- Sea level rise and coastal data.

Changes in these climate variables may exacerbate existing issues while also producing new problems for the utility. While all Global Circulation Models (GCMs) project warming, the projected changes in precipitation vary widely across the 38 GCMs used to generate climate projections in CREAT. Some models project wetter conditions for a given location while others project drier conditions. Climate models also vary in the predicted change in intensity of heavy precipitation events, some project stormier conditions than others. Predicting storm intensity and frequency is particularly difficult due to sensitivity to local topographic, hydrologic, and meteorological conditions, resulting in greater uncertainty across models for this climate stressor. CREAT provides averages of projected data selected from 38 GCMs to provide data for 1) warmer and wetter, 2) hotter and drier, and 3) moderate future conditions at a resolution of 0.5 x 0.5-degree grid cells (approximately 30 x 30 miles). Projections for storm intensity are generated from a subset of the GCMs that contain storm scalars (22 models) describing changes in precipitation per degree of warming for storm events over a range of recurrence intervals. The list of models used in CREAT is provided in **Appendix B:** Models Used in Developing Climate DataThe models provide a variety of future conditions that illustrate the range of potential climate changes; no set of future conditions is more likely to occur than another.

As part of this module, representatives from NOAA's National Integrated Drought Information System (NIDIS) and the Office of Coastal Management presented on drought and sea level rise, respectively. NOAA representatives introduced a variety of tools and answered questions about MBTS's historic climate trends and projections. MassDEP also provided regional climate information. A full list of tools presented is included in **Appendix F**: Climate Tools

Baseline Scenario

The default values in the Baseline Scenario used in CREAT are generated from historical observed climate data using the following methods (described in more detail in **Appendix C**):

- For Temperature and Precipitation – Average annual and monthly conditions are derived from the Parameter-elevation Regressions on Independent Slopes Model[2] (PRISM) dataset using historical observed data from 1981 to 2010.

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[2] PRISM Climate Group, Oregon State University. Available online at: **http://www.prism.oregonstate.edu/**

- For Intense Precipitation Events – Generated based on time-series analyses of historical climate data from NOAA's National Climate Data Center climate stations. Users can select the most relevant station; otherwise, the closest is automatically selected.
- For Historical Streamflow – Generated from approximately 8,200 U.S. Geological Survey stream gaging sites with daily discharge information covering the period of record.
- For Coastal Data – The projected sea-level rise and flood scenarios are derived from models produced by NOAA and published in a series of two reports which describe sea-level rise scenarios and flood inundation frequency at select locations. Coastal Data was not utilized within MBTS's CREAT assessment.

Additional details on the development of historical climate conditions and extreme events are provided in the CREAT 3.0 Methodology Guide, available on the CREAT website[3].

MBTS chose to consider the following variables in their assessment: average annual temperature; average temperature by month (June through September, as well as the month of January); number of hot days over 90 °F (annual); number of hot days over 95°F (annual); number of hot days over 100 °F (annual); total annual precipitation (inches); total precipitation by month (inches; June through September as well as January); 10-year intense precipitation event (inches/24hr); 10-year intense precipitation event (inches/72hr) 15-year intense precipitation event (inches/24hr); and 15-year intense precipitation event (inches/72hr); vertical land movement (inches/yr); sea level rise (feet); and number of days with tidal flooding.

The Baseline Scenario is pre-populated with default values by CREAT using the methods outlined above, but the user is given the option to provide custom data if available. At the suggestion of MassDEP, MBTS updated some values with data from Resilient MA[4] since the data is more recent and scaled to individual water basins. The updated values include: number of hot days over 90°F changed from 2 to 7.4; number of hot days over 95°F changed from 0 to 0.6; average annual temperature from 48.9 to 50.2°F; and total annual precipitation from 46.87 in to 45.3 in. **Table 1** shows the selected Baseline Scenario values.

Projected Scenario

In addition to the Baseline Scenario, a projected scenario was created based on projected climate data: a **Hotter, Drier Future Scenario** characterized as hot, dry, historical storminess, and high sea level rise. MBTS reviewed the CREAT projections data to confirm that the data seemed reasonable. **Table 1** shows the selected Projected Scenario values drawn from default CREAT data.

[3] CREAT 3.0 Methodology Guide is available at **https://www.epa.gov/crwu/creat-risk-assessment-application-water-utilities**
[4] Resilient MA Climate Change Clearinghouse. Available at: https://resilientma.mass.gov/map/

Table 1. Historical and Projected Climate Data for the MBTS Assessment

Measurement	Baseline	Hotter and Drier Future
Annual Average Temperature (Fahrenheit)	50.20	--
January Average Temperature (Fahrenheit)	26.65	--
June Average Temperature (Fahrenheit)	65.80	--
July Average Temperature (Fahrenheit)	71.06	--
August Average Temperature (Fahrenheit)	69.54	--
September Average Temperature (Fahrenheit)	62.02	--
Annual Degree Change in temperature (Fahrenheit)	--	5.04
January Degree Change in temperature (Fahrenheit)	--	5.20
June Degree Change in temperature (Fahrenheit)	--	4.53
July Degree Change in temperature (Fahrenheit)	--	5.26
August Degree Change in temperature (Fahrenheit)	--	5.48
September Degree Change in temperature (Fahrenheit)	--	5.46
Annual Number of hot days over 90 °F (Days)	7	18
Annual Number of hot days over 95 °F (Days)	0	5
Annual Number of hot days over 100 °F (Days)	0	1
Annual Total Precipitation (Inches)	45.30	--
January Total Precipitation (Inches)	4.15	--
June Total Precipitation (Inches)	3.67	--
July Total Precipitation (Inches)	3.41	--
August Total Precipitation (Inches)	3.39	--
September Total Precipitation (Inches)	3.85	--
Annual % Change in precipitation (%)	--	2.21

January % Change in precipitation (%)	--	1.38
June % Change in precipitation (%)	--	1.16
July % Change in precipitation (%)	--	0.74
August % Change in precipitation (%)	--	1.64
September % Change in precipitation (%)	--	-5.17
10-year storm event (Inches/24hr)	3.49	3.49
15-year storm event (Inches/24hr)	3.87	3.87
10-year storm event (Inches/72hr)	5.41	5.41
15-year storm event (Inches/72hr)	5.90	5.90
Annual Total Vertical Land Movement* (Inches/Yr)	-0.03	--
Total Sea Level Rise (Feet)	0.00	6.60
Annual Average Number of days with tidal flooding (Days)	7	365

Threat Definitions

The CREAT assessment is built around specific climate change threats of concern identified by the utility. MBTS described the two priority threats for the assessment as drought and water quality degradation. The team developed customized definitions for these threats as follows:

- **Drought – Lower pond and groundwater levels**
  Baseline Climate Scenario
  - Periods of minimal precipitation in summer, combined with seasonal demand increases, will lead to lower pond and groundwater levels that water utilities rely on for water supplies. In addition, evaporation rates and water loss from vegetation will be higher due to increasing temperatures. These lower levels may make it difficult to meet water demands, especially in summer months, and may drop water levels below intake infrastructure.

  Hotter, Drier Future
  - Periods of minimal precipitation and extreme heat in summer, combined with seasonal population increase and irrigation uses, will lead to lower surface and groundwater levels. In addition, evaporation rates and water loss from soil and vegetation will be higher due to increasing temperatures, further lowering the water table. Meeting demand is difficult to do in the summer. During extended periods of extreme heat and minimal precipitation, Gravelly Pond water levels decline below the level of intakes. Water quality also declines due to the disinfection challenges posed by increased temperature. Groundwater levels at the Lincoln Street Well also drop. It is unknown how long a period of high heat and low precipitation MBTS could endure and still meet current summer demand. Were Gravelly Pond

levels to decline to the point that it is unusable, current demand could not be met. Were the Lincoln Street Well to become unusable, it would also create significant challenges in meeting demand.

- **Water Quality Degradation - Saline intrusion into aquifers**
  Baseline Climate Scenario
  - No impacts under baseline conditions.

  Hotter, Drier Future
  - Projected sea-level rise can lead to saltwater intrusion in both coastal groundwater aquifers and estuaries. This combination may reduce water quality and increase treatment costs for water treatment facilities. Were the source to become brackish, the Lincoln Street Well could not be used. This would pose significant challenges in meeting summer demand and would also compromise the ability of Gravelly Pond water levels to recover during the winter months, i.e., when the Well has been the primary water source for the MBTS system.

Economic Consequences

The risk assessment framework in CREAT guides users through the process of assigning levels of economic consequences they would experience if climate change threats were to occur, and then adjusting those consequences if they were to be *reduced* through the implementation of adaptation options that protect utility assets.

CREAT provides economic consequence data related to four categories that capture the range of impacts a water utility may experience from a climate-related threat:

- **Utility Business Impacts** – Operating revenue loss evaluated in terms of the magnitude and recurrence of service interruptions. Consequences range from long-term loss of expected operating revenue to minimal potential for any loss.
- **Utility Equipment Damage** – Costs of replacing the service equivalent provided by a utility or piece of equipment evaluated in terms of the magnitude of damage and financial impacts. Consequences range from complete loss of the asset to minimal damage to the equipment.
- **Environmental Impacts** – Evaluated in terms of environmental damage or loss, aside from water resources, and compliance with environmental regulations. Consequences range from significant environmental damage to minimal impact or damage.
- **Source/Receiving Water Impacts** – Degradation or loss of source or receiving water quality or quantity evaluated in terms of recurrence. Consequences range from long-term compromise to no more than minimal changes to water quality or quantity.

MBTS chose to consider and monetize the following economic consequence categories: **Utility Business Impacts, Utility Equipment Damage, Environmental Impacts,** and **Source/Receiving Water Impacts**. MBTS included Utility Business Impacts as revenue impacts could result from the threats. MBTS included Utility Equipment Damage as they face issues associated with aging equipment. MBTS included Environmental Impacts as they face costs related to environmental regulatory fines. The MBTS team chose to keep the default definitions provided by CREAT for each consequence category.

Consequence Cost Ranges

CREAT provides default cost ranges within each category based on historical cost and expenditure data from utilities of similar size and economic condition that represent Low, Medium, High, and Very High impacts to the utility. The economic data is based on water sector survey data and calculated using the utility type (water vs. wastewater), population served, total daily flow, public or private ownership, and financial condition. Default CREAT values can be revised by a user to better reflect the utility's financial data.

MBTS kept the default ranges of economic values for all categories except **Utility Business Impacts**. For this category, MBTS found that the default ranges were too large for their system's operating budget, particularly, that the upper threshold of the Low consequence category would be a significant impact to their budget. Their annual O&M budget is about $1.2M. They could perhaps weather a 1-3% loss with minimal impacts, but more than that would have significant implications. MBTS decided to set the upper bound of the Low category at 3% of their O&M budget, or $36,000. Changes were made across every level of each category to better reflect the cost ranges associated with these levels of financial impact on the system. It should be noted that there is not an upper bound to the Very High category: while this level of impact could be felt at lower threshold, it does not describe the maximum extent of impacts that could be incurred. The categories and monetary ranges associated with the levels of consequences can be found in **Table 2.**

Table 2 MBTS Economic Consequence Matrix

Consequence Categories	Levels and Annual Costs			
	Low	**Medium**	**High**	**Very High**
Utility Business Impacts	Operating revenue loss is evaluated in terms of the magnitude and recurrence of service interruptions. Consequences range from long-term loss of expected operating revenue to minimal potential for any loss.			
	Minimal potential for loss of revenue or operating income	*Minor and short-term reductions in expected revenue*	*Seasonal or episodic compromise of expected revenue or operating income*	*Long-term or significant loss of expected revenue or operating income*
	$0 - $36,000	$36,000 - $60,000	$60,000 - $84,000	$84,000+
Utility Equipment Damage	Costs of replacing the service equivalent provided by a utility or piece of equipment evaluated in terms of the magnitude of damage and financial impacts. Consequences range from complete loss of the asset to minimal damage to the equipment.			
	Minimal damage to equipment	*Minor damage to equipment*	*Significant damage to equipment*	*Complete loss of asset*
	$0 - $30,000	$36,000 - $146,000	$146,000 - $349,000	$349,000+
Environmental Impacts	Evaluated in terms of environmental damage or loss, aside from water resources, and compliance with environmental regulations. Consequences range from significant environmental damage to minimal impact or damage.			
	No impact or environmental damage	*Short-term damage, compliance can be quickly restored*	*Persistent environmental damage*	*Significant environmental damage*
	$0 - $4,845	$4,845 - $12,189	$12,189 - $29,223	$29,223+
Source/Receiving Water Impacts	Degradation or loss of source or receiving water quality or quantity evaluated in terms of recurrence. Consequences range from long-term compromise to no more than minimal changes to water quality or quantity.			

	No more than minimal changes to water quality	*Temporary impact on source water quality or quantity*	*Seasonal or episodic compromise of source water quality or quantity*	*Long-term compromise of source water quality or quantity*
	$0 - $20,859	$20,859 - $52,173	$52,173 - $125,154	$125,154+

Regional Economic Consequence Assessment

Often in risk assessments, financial consequences extend solely to the entity that is conducting the risk assessment. When studying public utilities, however, the impact of climate risks often extends to those who rely on a public utility for their services. Regional economic consequence estimates in CREAT include lost revenue from businesses and industries in the utility's area that cannot operate due to service disruptions. For each asset/threat pair, CREAT estimates state-level economic consequences for business activity in the utility's service area that are impacted by disruption and allows for the possibility that only a portion of the utility's service may be impacted by disruption from any given asset/threat pair. The magnitude of Regional Economic Consequences is linked to the duration and extent of the disruption in normal services.

EPA encouraged MBTS to consider regional consequences since water outages had been experienced before and therefore may be expected to impact the community in the future. The economic consequences borne directly by the utility might be relatively small in comparison to economic and public health impacts borne by the community.

MBTS decided to include Regional Economic Consequences in their assessment.

Public Health Consequence Assessment

Within risk assessment frameworks, most experts have chosen to try to separate out the potential economic impact of death and injury. AWWA and other standard development organizations have included public health consequences to define economic consequences in the context of risk mitigation to help justify investment. The default values in CREAT, which are based on the EPA's Guidelines for Preparing Economic Analyses, calculate the value of statistical life to be $7,900,000 and the value of statistical injury to be $79,000.

MBTS chose not to include public health consequences in their assessment, due to the uncertainties associated with quantifying injuries and loss of life.

Risk Assessment and Adaptation Options

CREAT risk assessments are conducted on pairs of utility assets and climate change threats, or "Asset/Threat Pairs." For this assessment, MBTS explored the impacts of drought and water quality degradation on Gravelly Pond and the Lincoln Street Well, as shown in **Table 3**. Using CREAT, MBTS was able to assess the consequences they may experience if flooding occurred at or around the WTP, given its current capabilities and the risk reduction of different Adaptation Plans that could be implemented in the future.

Table 3 MBTS Asset/Threat Pairs with Relevant Consequence Categories

CRITICAL ASSET	PAIRED THREAT(S)	CONSEQUENCE CATEGORIES
Gravelly Pond *Associated Water Treatment Plant, Round Pond*	Drought, Water Quality Degradation	Utility Business Impacts Utility Equipment Damage Environmental Impacts Source/Receiving Water Impacts Regional Economic Consequences
Lincoln Street Well *Associated aquifer*	Drought, Water Quality Degradation	Utility Business Impacts Utility Equipment Damage Environmental Impacts Source/Receiving Water Impacts Regional Economic Consequences

To investigate potential risk reduction, MBTS evaluated both Existing Adaptive Measures and Potential Adaptive Measures.

Existing Adaptive Measures are grouped into a "Current Measures" Adaptation Plan in CREAT and represent MBTS' current capabilities to respond to and recover from threats. The cost associated with the Current Measures Adaptation Plan totals $1 million; these costs are not used in the Risk Assessment calculations because they have already occurred; they are considered as sunk costs. Implementation costs for Existing Adaptive Measures can be included for accounting purposes or to capture previous and current investments in measures that increase climate resilience.

The descriptions and costs for each adaptive measure are provided in **Appendix D**; Existing Adaptive Measures are defined in **Table D-1**, and Potential Adaptive Measures are defined in **Table D-2.**

The three Potential Adaptive Measures that MBTS evaluated are shown in **Table 4**. The Adaptation Plans, which focus on each individual adaptive measure, are in **Table 5**. The MBTS team opted for each adaptive measure to serve as a separate Adaptation Plan since the adaptive measures are large in scope. It is important to note that the Interconnection Plan assumes that the neighboring community of Beverly will have water to sell to MBTS, and that the New Well Plan assumes the New Well is not impacted by the quantity and/or quality challenges faced by the Lincoln Street Well in a Hotter, Drier Future Scenario.

Table 4 MBTS Potential Adaptive Measures and Associated Annual Costs

POTENTIAL ADAPTIVE MEASURE	ASSOCIATED ANNUAL COST
Interconnections	$700,000 - $2,555,000
New Well	$77,000 - $772,000
Watershed protection	$10,000 - $114,000

Table 5 MBTS Adaptation Plans and Associated Annual Costs

ADAPTATION PLAN	DEFINITION	ADAPTATION PLAN ANNUAL COST
Current Measures	Existing adaptive measures.	$1,000,000
Interconnections	Expand and utilize interconnections with City of Beverly to purchase water	$700,000 - $2,555,000
New Well	Acquire a new well	$77,000 - $772,000
Watershed Protection	Expand watershed protection through land acquisition and/or expansion of source water protection overlay	$10,000 - $114,000

In consideration of other potential adaptive measures, MBTS discussed findings from the Water Resources Protection Task Force's ("Task Force") ongoing work. The Town noted that there is a list of potential alternative sources (i.e., "capped wells near Gravelly and Round Ponds, old wells near Cedar Swamp/Sawmill Brook, new wells, sharing with neighboring towns, tying into MWRA/Quabbin, tapping into Gloucester, private wells, etc.") that came about from a brainstorming exercise led by the Chair of the Conservation Commission and Chair of the Task Force. Because the purpose of the list was exploratory and the Task Force is in such early stages, the MBTS team chose not to evaluate these ideas as potential adaptive measures in the CREAT assessment.

CREAT Assessment Results

CREAT guides users through a risk assessment for each asset/threat pair across all the defined climate scenarios. Each assessment considers the implementation of a specific Adaptation Plan. The assessment results for each potential Adaptation Plan can be compared to the results from the assessment of the Current Measures plan to show the benefits of the Potential Adaptive Measures. During the risk assessment, MBTS evaluated the potential risk reduction offered by each Adaptation Plan relative to the cost of implementing that plan for each defined scenario (Baseline, Moderate Future Conditions, and Extreme Precipitation). The main goal of adaptation is to reduce the consequences of climate change threats. For each scenario and Adaptation Plan, MBTS selected the expected climate threat impact level (Low to Very High) in the Economic Consequences Matrix (see **Table 2**). The Baseline Scenario under Current Measures Plan is considered to be the case against which to evaluate the potential benefits of individual Adaptation Plans. By definition, adaptive measures should decrease consequences, and MBTS determined the expected level of impact assuming an Adaptation Plan was implemented.

The Current Measures assessment for the Baseline Scenario represents the consequences that MBTS may experience in damages or costs due to drought or water quality degradation assuming only existing capacity to respond to and recover from climate change and related events. By evaluating the Current Measures plan for the projected Hotter, Drier Future Scenario, MBTS can understand potential consequences if the climate were to change but no additional adaptive measures were to be implemented. The assessment of each Adaptation Plan provides the total consequences (in dollars) that MBTS may experience after implementing Adaptation Plans, both for historical conditions as defined in the Baseline Scenario, and for the projected future climates defined in the Hotter, Drier Future Scenario. Potential risk reduction achieved by the implementation of various adaptive measures is determined by evaluating the change in expected climate impact level or consequences for each Adaptation Plan and comparing the results with those for Current Measures for each scenario. The assumptions underlying the team's determination of consequence levels and public health consequences are described in **Appendix E.**

Economic Consequences

CREAT calculates monetized risk reduction from the asset/threat pair assessment to characterize the difference between current and potential future risk to utility assets and resources and the associated regional economic impacts, with and without adaptation. Monetized risk reduction is the change in total consequences considering the increased capabilities of assets to withstand the impacts from threats following the implementation of an Adaptation Plan, including both risks to the utility and greater regional risks. For example, the combined annual risk reduction from the Interconnection Plan for both the utility itself and the region under a Hotter, Drier Scenario was calculated to be as great as $279 million. This plan would cost between $700,000 and $2,555,000[5] to implement on an annualized basis. By comparing the cost of implementation to the associated benefits, MBTS can determine the cost effectiveness of implementing different Adaptation Plans. It should be noted that, while the costs to implement an Adaptation Plan are borne directly by the utility, the resulting risk reduction benefits both the utility and the community. Annual Adaptation Plan cost, potential total economic consequences for the utility and the region, and monetized risk reductions for each Adaptation Plan are shown in **Table 6-7.** These tables present annual values *assuming the threat (drought or saltwater intrusion) occurs.*

[5] Implementation costs were calculated using MBTS's current commercial rate of $.014/gal, with the minimum representing the costs for purchasing 50 MG due to drought impacts to Gravelly Pond, and the maximum representing the costs for purchasing 0.5MGD from taking the Lincoln Street well out of production due to saltwater intrusion.

Table 6 MBTS Adaptation Plans Consequences and Risk Reduction – Combined Utility and Regional Economic Consequences

ADAPTATION PLAN	BASELINE SCENARIO		HOTTER, DRIER FUTURE CONDITIONS	
NAME	ANNUALIZED TOTAL CONSEQUENCES	ANNUALIZED RISK REDUCTION	ANNUALIZED TOTAL CONSEQUENCES	ANNUALIZED RISK REDUCTION
Current Measures (No Change) **Annual Cost: $1,000,000**	$2,719,065 - $3,086,835	N/A	> $373,370,613	N/A
Interconnections **Annual Cost: $700,000 - $2,555,000**	$0 - $366,816	$2,657,361 - $2,781,723	$93,287,581 - $93,917,758	> $279,606,199
New Well **Annual Cost: $77,000 - $772,000**	$0 - $366,816	$2,657,361 - $2,781,723	$25,828,817 - $26,379,996	> $347,136,617
Watershed Protection **Annual Cost: $10,000 - $114,000**	$0 - $366,816	$2,657,361 - $2,781,723	> $366,907,741	> $6,224,187

Table 7 MBTS Adaptation Plans Consequences and Risk Reduction Utility and Regional Economic Consequences Breakdown

THREAT ASSET PLAN	ANNUALIZED UTILITY RISK REDUCTION		ANNUALIZED REGIONAL RISK REDUCTION	
	BASELINE	HOTTER, DRIER	BASELINE	HOTTER, DRIER
Drought Lincoln St. Well, Aquifer Interconnections	$61,704 - $62,658	$176,673 +	$2,657,361	$26,099,079
Drought Lincoln St. Well, Aquifer New Well	$61,704 - $62,658	$176,673 +	$2,657,361	$25,150,021
Drought Lincoln St. Well, Aquifer Watershed Protection	$61,704 - $62,658	$0	$2,657,361	$0
Water Quality Degradation Lincoln St. Well, Aquifer Interconnections	$0	$348,329	N/A	$207,843,568
Water Quality Degradation Lincoln St. Well, Aquifer New Well	$0	$495,673 +	N/A	$277,124,758
Water Quality Degradation Lincoln St. Well, Aquifer Watershed Protection	$0	$0	N/A	$0
Drought Gravelly Pond, Round Pond, Water Treatment Plant Interconnections	$0	$91,314 - $120,981	N/A	$37,962,296
Drought Gravelly Pond, Round Pond, Water Treatment Plant New Well	$0	$96,159 - $128,325	N/A	$37,962,296
Drought Gravelly Pond, Round Pond, Water Treatment Plant Watershed Protection	$0	$57,018 - $111,639	N/A	$0
Water Quality Degradation Gravelly Pond, Round Pond, Water Treatment Plant Interconnections	$0	$96,981 +	N/A	$7,117,931
Water Quality Degradation Gravelly Pond, Round Pond, Water Treatment Plant New Well	$0	$96,981 +	N/A	$6,168,873

Water Quality Degradation Gravelly Pond, Round Pond, Water Treatment Plant Watershed Protection	$0	$6,966 +	N/A	$6,168,873

While all Adaptation Plans would provide a level of resilience to one or both threats considered, the extent of benefits and cost-effectiveness of projects will be greater under a more extreme future climate (higher temperatures, less precipitation, higher sea level rise). Initial CREAT assessment results suggest that implementing potential adaptive measures could be cost-effective in terms of monetized risk reduction under the Hotter, Drier Future Scenario. In a milder climate scenario, such as the Baseline Scenario, results suggest all three Potential Adaptation Plans (i.e., utilizing interconnections with Beverly, acquiring a new well, and increasing watershed protection) could have modest monetized risk reductions. In a more extreme climate future, like in the Hotter, Drier Scenario, results suggest the Interconnections and New Well Adaptation Plans could significantly reduce monetized risk. The Watershed Protection Adaptation Plan under the Hotter, Drier Future Scenario may provide some benefit in preventing development of incompatible uses in the source water protection areas, which could exacerbate climate impacts, but it would not in itself significantly reduce the impacts of drought or saltwater intrusion to the utility. This CREAT assessments did not evaluate the potential for land use change in the future, which would compound climate impacts.

Regional Economic Consequences

The estimates for annual Regional Economic Consequences for each asset/threat pair are provided in **Tables 8-12.** Regional economic consequence estimates in CREAT include lost revenue from business and industries in the utility's area that cannot operate due to water service disruptions. The magnitude of Regional Economic Consequences is linked to the *duration* and *extent* of the disruption in normal services. These consequences are estimated using a multi-sector, inter-industry framework within CREAT.

Table 8 Adaptation Plans and Associated Regional Economic Consequences Combined Assessment

ADAPTATION PLAN	BASELINE SCENARIO	Hotter, Drier Future
	REGIONAL ECONOMIC CONSEQUENCE	REGIONAL ECONOMIC CONSEQUENCE
Current Measures (No Change) - $1,000,000	$2,657,361	$372,030,498
Interconnections $700,000 - $2,555,000	$0	$93,007,624
New Well $77,000 - $772,000	$0	$25,624,550
Watershed Protection $10,000 - $114,000	$0	$365,861,625

Table 9 Adaptation Plans and Associated Regional Economic Consequences Lincoln Street Well / Drought

ADAPTATION PLAN	BASELINE SCENARIO		Hotter, Drier Future	
	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE
Current Measures (No Change) - $1,000,000	14, 10%	$2,657,361	30, 50%	$28,471,722
Interconnections $700,000 - $2,555,000	0, 0%	$0	5, 25%	$2,372,643
New Well $77,000 - $772,000	0, 0%	$0	7, 25%	$3,321,701
Watershed Protection $10,000 - $114,000	0, 0%	$0	30, 50%	$28,471,722

Table 10 Adaptation Plans and Associated Regional Economic Consequences Lincoln Street Well / Water Quality Degradation

ADAPTATION PLAN	BASELINE SCENARIO		Hotter, Drier Future	
	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE
Current Measures (No Change) - $1,000,000	0, 0%	$0	365, 40%	$277,124,758
Interconnections $700,000 - $2,555,000	0, 0%	$0	365, 10%	$69,281,190
New Well $77,000 - $772,000	0, 0%	$0	0, 0%	$0
Watershed Protection $10,000 - $114,000	0, 0%	$0	365, 40%	$277,124,758

Table 11 Adaptation Plans and Associated Regional Economic Consequences Gravelly Pond / Drought

ADAPTATION PLAN	BASELINE SCENARIO		Hotter, Drier Future	
	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE
Current Measures (No Change) - $1,000,000	0, 0%	$0	100, 30%	$56,943,444
Interconnections $700,000 - $2,555,000	0, 0%	$0	100, 10%	$18,981,148
New Well $77,000 - $772,000	0, 0%	$0	100, 10%	$18,981,148
Watershed Protection $10,000 - $114,000	0, 0%	$0	100, 30%	$56,943,444

Table 12 Adaptation Plans and Associated Regional Economic Consequences Gravelly Pond / Water Quality Degradation

ADAPTATION PLAN	BASELINE SCENARIO		Hotter, Drier Future	
	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE	DAYS AND PERCENT OF CUSTOMERS WITHOUT SERVICE	REGIONAL ECONOMIC CONSEQUENCE
Current Measures (No Change) - $1,000,000	0, 0%	$0	10, 50%	$9,490,574
Interconnections $700,000 - $2,555,000	0, 0%	$0	5, 25%	$2,372,643
New Well $77,000 - $772,000	0, 0%	$0	7, 25%	$3,321,701
Watershed Protection $10,000 - $114,000	0, 0%	$0	7, 25%	$3,321,701

Risk Assessment

Based on the results of the CREAT assessment, all MBTS's Adaptation Plans (i.e., utilizing interconnections to bring water from Beverly, establishing or acquiring a new well, and increasing watershed protection) are cost-effective in terms of monetized risk reduction under a Hotter, Drier Future Scenario, although the degree of impact varies by Plan. The Interconnections and New Well Plans have the most significant monetized risk reduction potential under this more extreme climate future, as seen in **Figure 2** and **Figure 4**, respectively. As these figures show, the CREAT assessment projects that the Interconnection Plan would result in combined utility and regional risk reductions valued at more than $279,606,199, and that the New Well Plan would have monetized risk reductions exceeding $347,136,617. The

Watershed Protection Plan, as seen in **Figure 6**, has the potential for a more modest monetized risk reduction. Although the Adaptation Plans are all projected to have varying degrees of cost effectiveness under a Hotter and Drier Future Scenario, this is not necessarily the case under a Baseline Scenario.

There is a high potential for loss under a Hotter, Drier Future Scenario, as seen in the **Table 6-7**, which show considerable risks to all of MBTS's considered assets under a Hotter, Drier Future Scenario. Total Regional Economic Consequences under this scenario would also be significant, and as seen in **Table 8-12** above.

Figures 1-18 (below) present an overview of the CREAT assessment results under Baseline Conditions and a Hotter, Drier Future Scenario and for each of MBTS's asset (i.e., Gravelly Pond, Round Pound and Water Treatment Plant & Lincoln Street Well and Aquifer), as well as a combined assessment of both assets under the two scenarios. For each Adaptation Plan, the range of values for total consequences for the Current Measures ("No Change") and Adaptation Plan are shown (red and yellow, respectively), as well as total monetized risk reduction and Adaptation Plan cost (green and gray, respectively). These figures present combined results that include the risk borne by the utility, alongside Regional Economic Consequences.

Figure 1 Risk Assessment. All Assets, Baseline Scenario, Interconnections

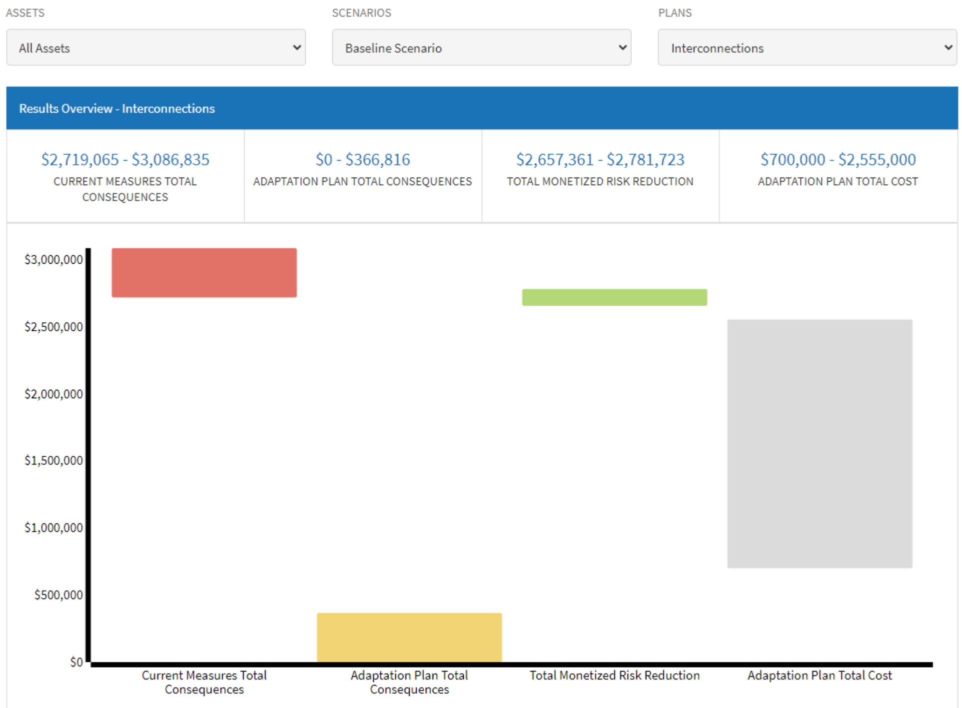


Figure 2 Risk Assessment. All Assets, Hotter and Drier Future Scenario, Interconnections

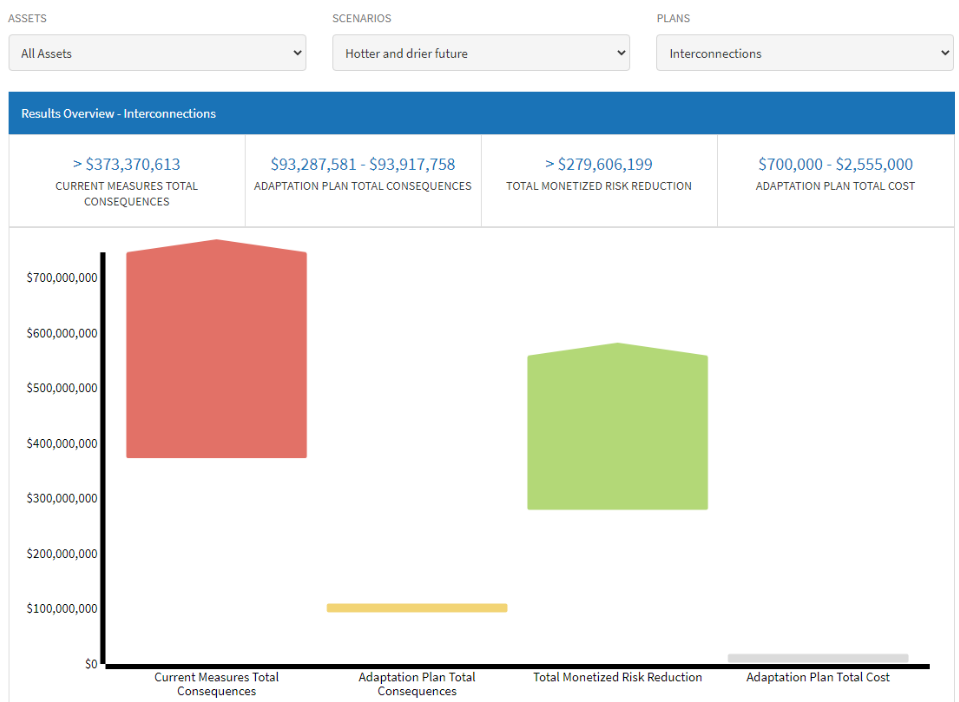


Figure 3 Risk Assessment. All Assets, Baseline Scenario, New Well

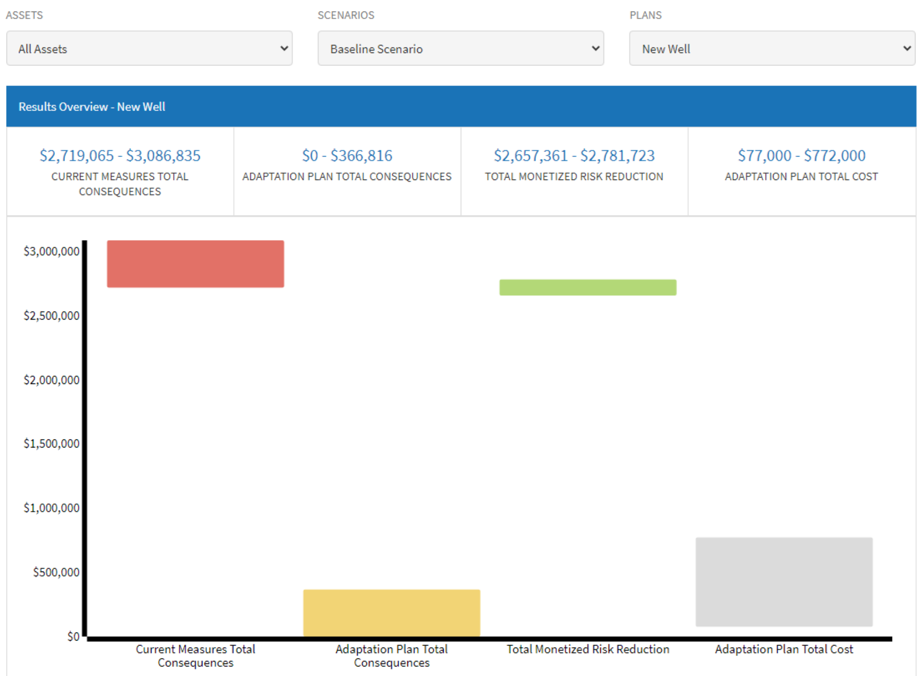


Figure 4 Risk Assessment. All Assets, Hotter and Drier Future Scenario, New Well

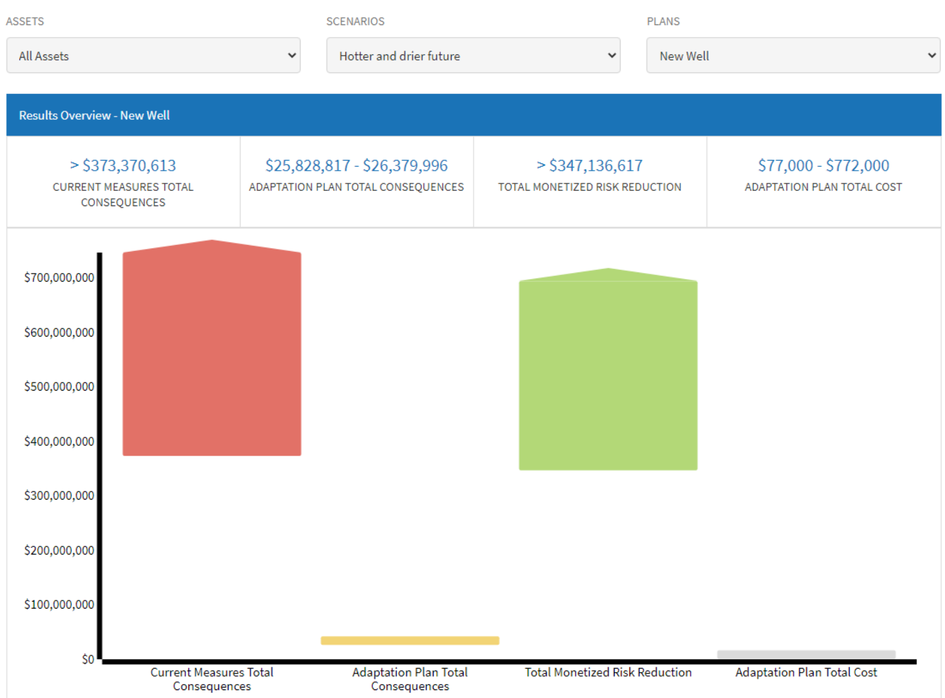


Figure 5 Risk Assessment. All Assets, Baseline Scenario, Watershed Protection

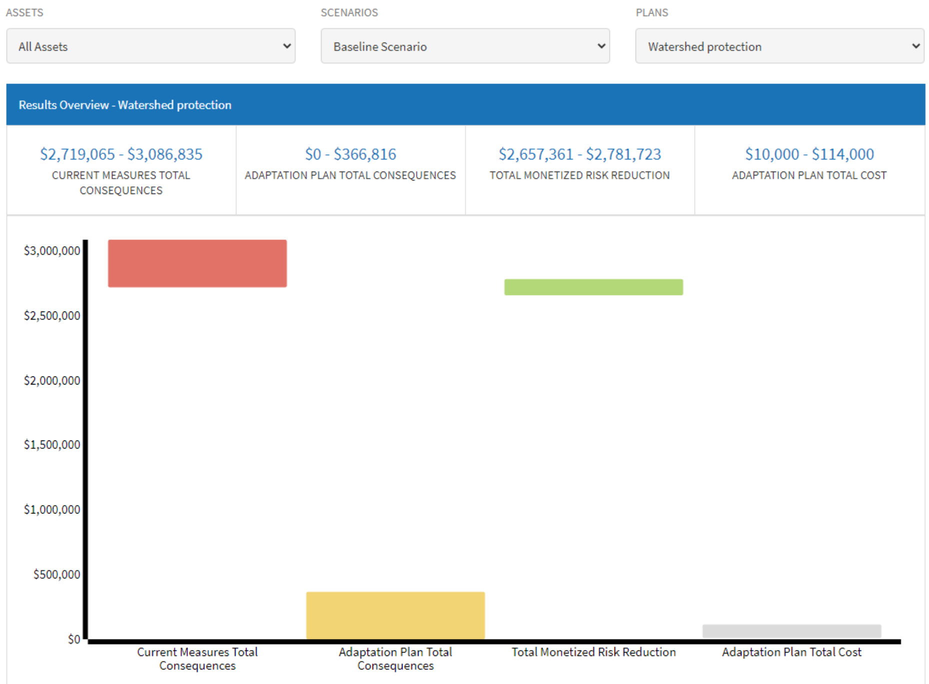


Figure 6 Risk Assessment. All Assets, Hotter and Drier Future, Watershed Protection

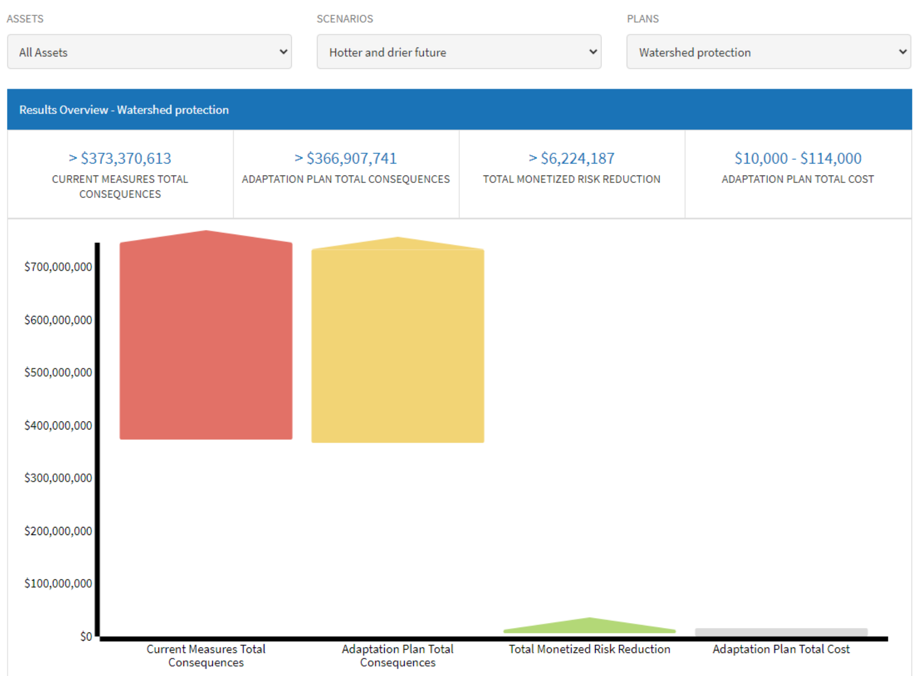


Figure 7 Risk Assessment. Lincoln Street Well and Aquifer, Baseline Scenario, Interconnections

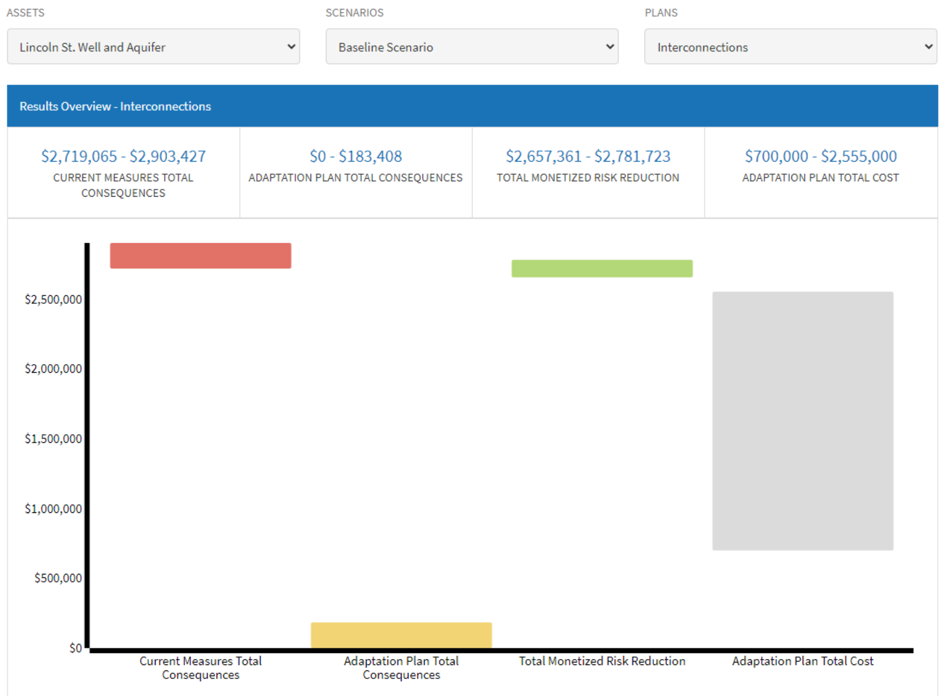


Figure 8 Risk Assessment. Lincoln Street well and Aquifer, Hotter and Drier Future, Interconnections

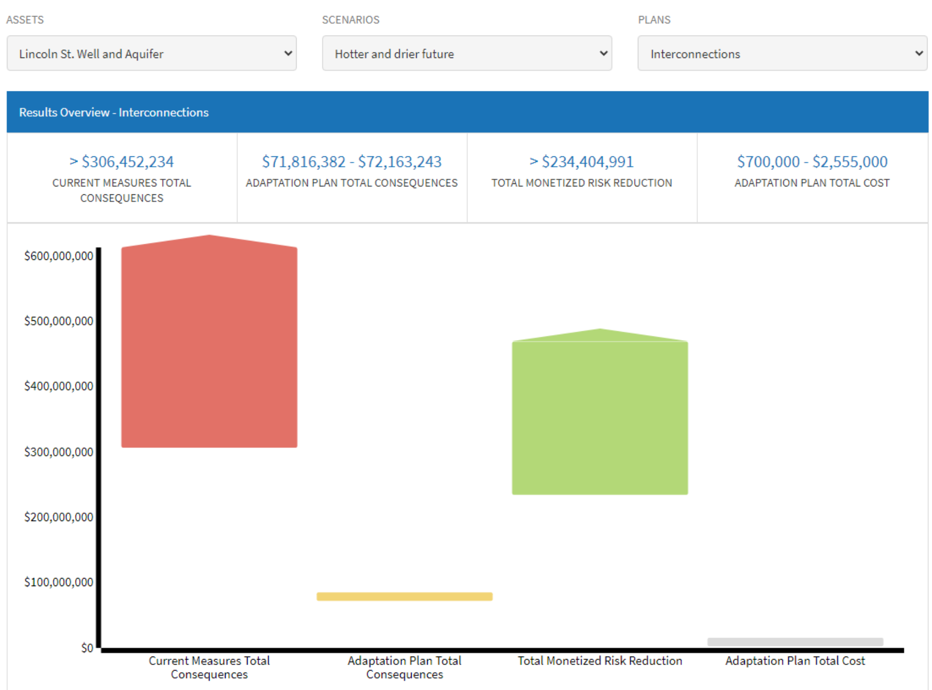


Figure 9 Risk Assessment Lincoln Street Well and Aquifer, Baseline Scenario, New well

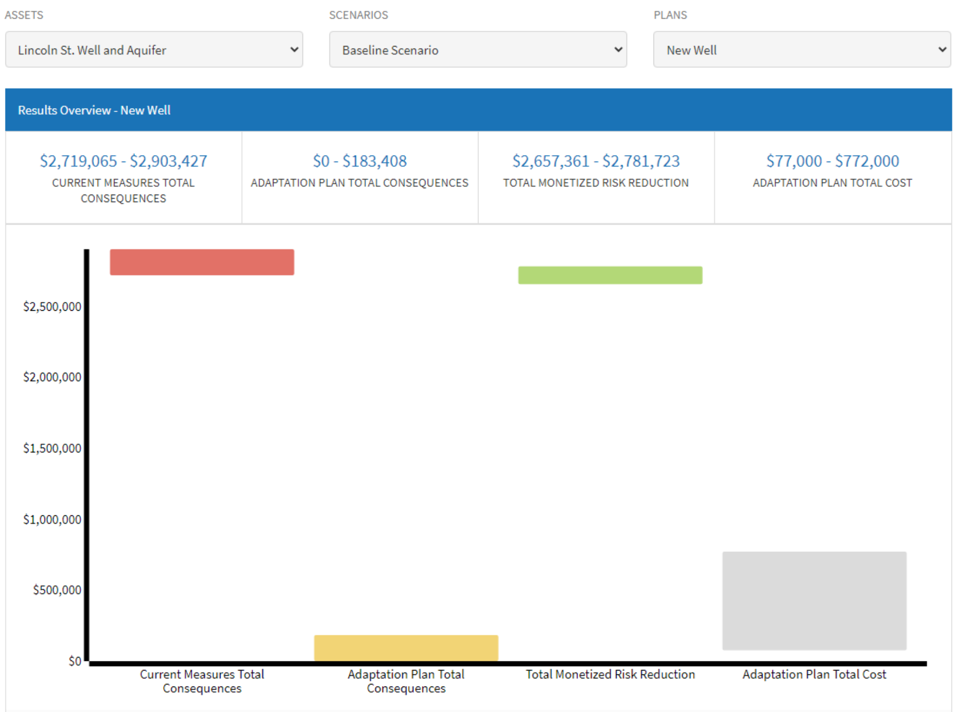


Figure 10 Risk Assessment Lincoln Street Well and Aquifer, Hotter and Drier Future Scenario, New well

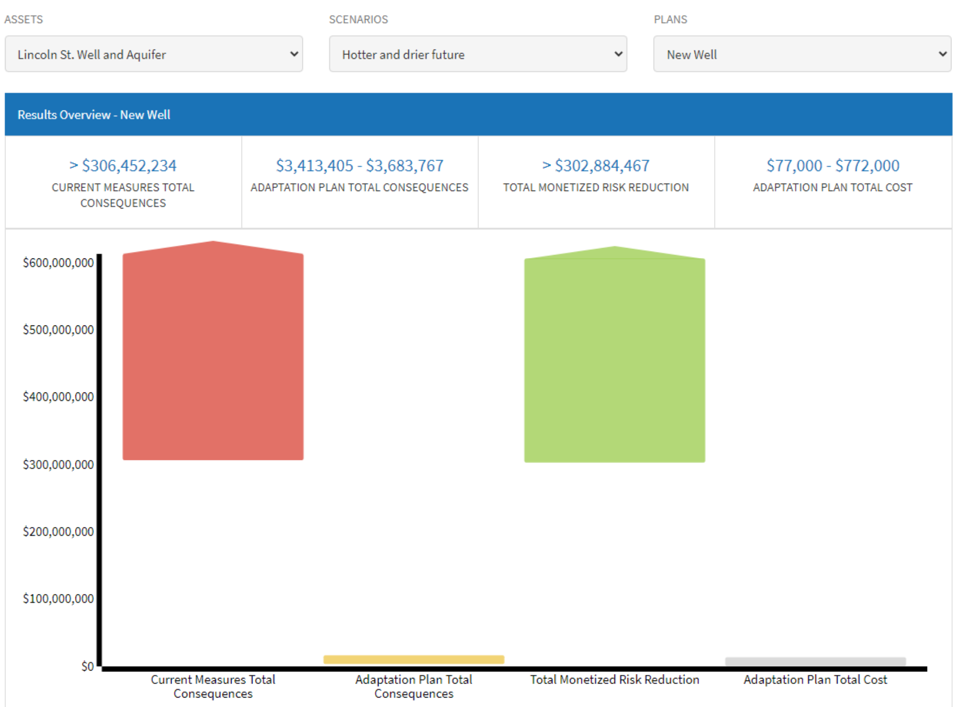


Figure 11 Risk Assessment. Lincoln Street Well and Aquifer, Baseline Scenario, Watershed Protection

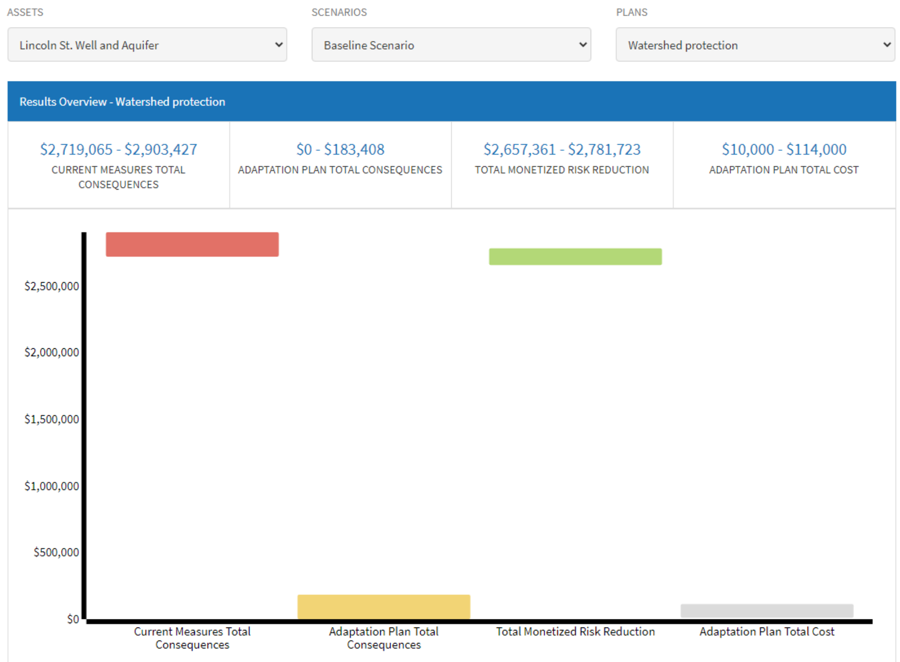


Figure 12 Risk Assessment. Lincoln Street Well and Aquifer, Hotter and Drier Future Scenario, Watershed Protection

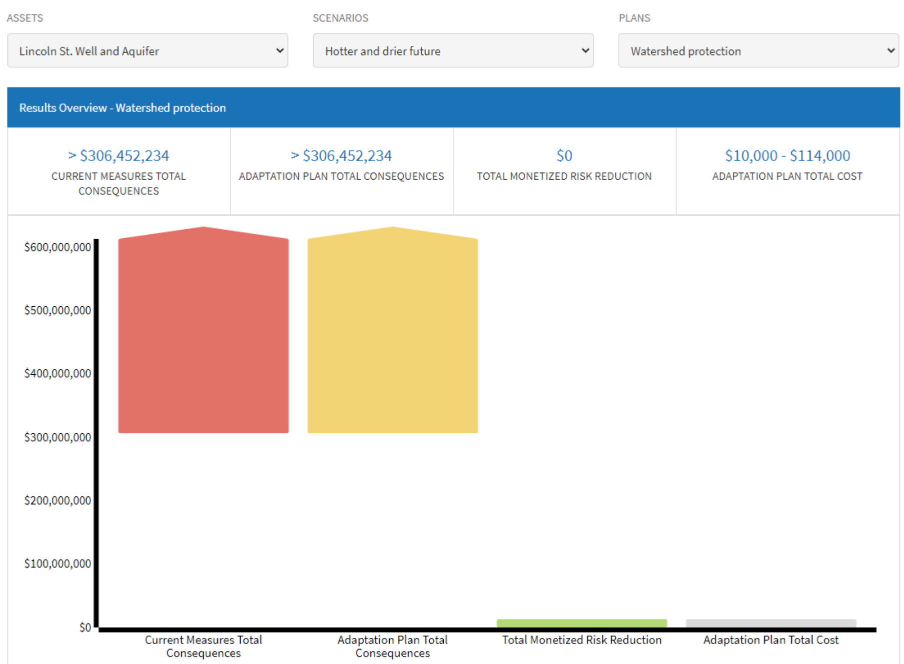


Figure 13 Risk Assessment. Gravelly Pond, Baseline Scenario, Interconnections

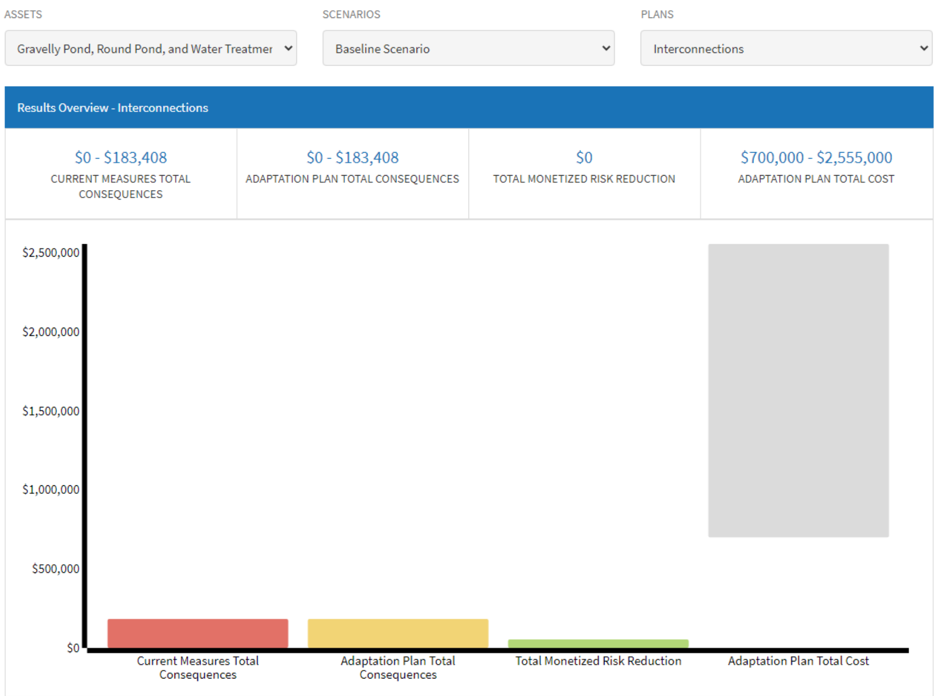


Figure 14 Risk Assessment. Gravelly Pond, Hotter and Drier Future Scenario, Interconnections

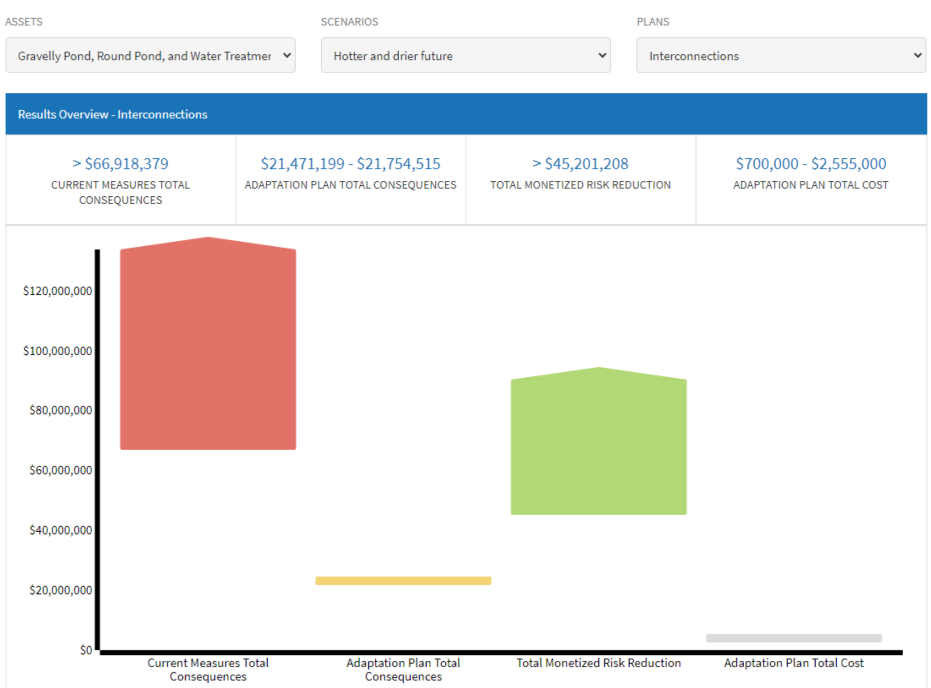


Figure 15 Risk Assessment. Gravelly Pond, Baseline Scenario, New Well

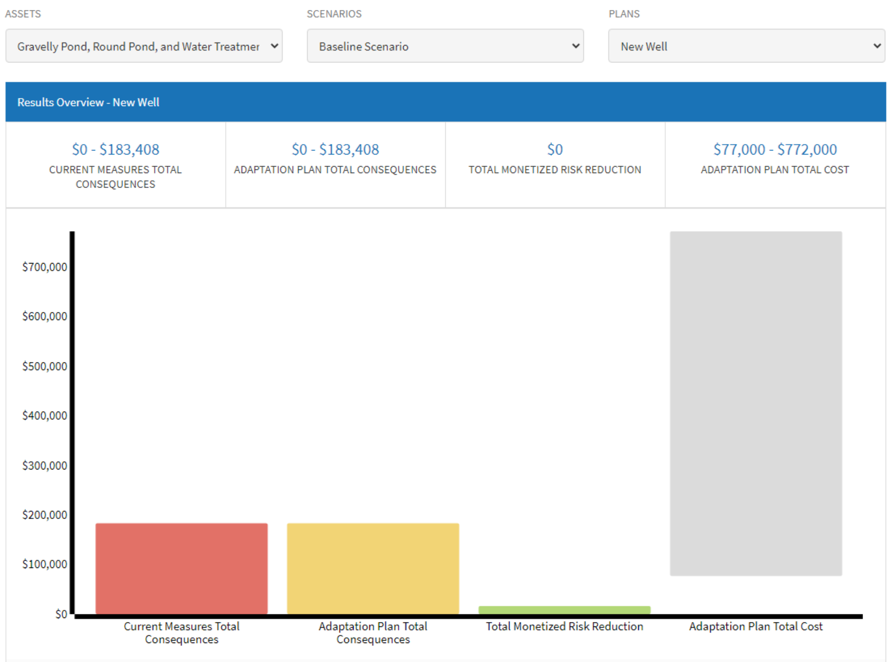


Figure 16 Risk Assessment. Gravelly Pond, Hotter and Drier Future Scenario, New Well

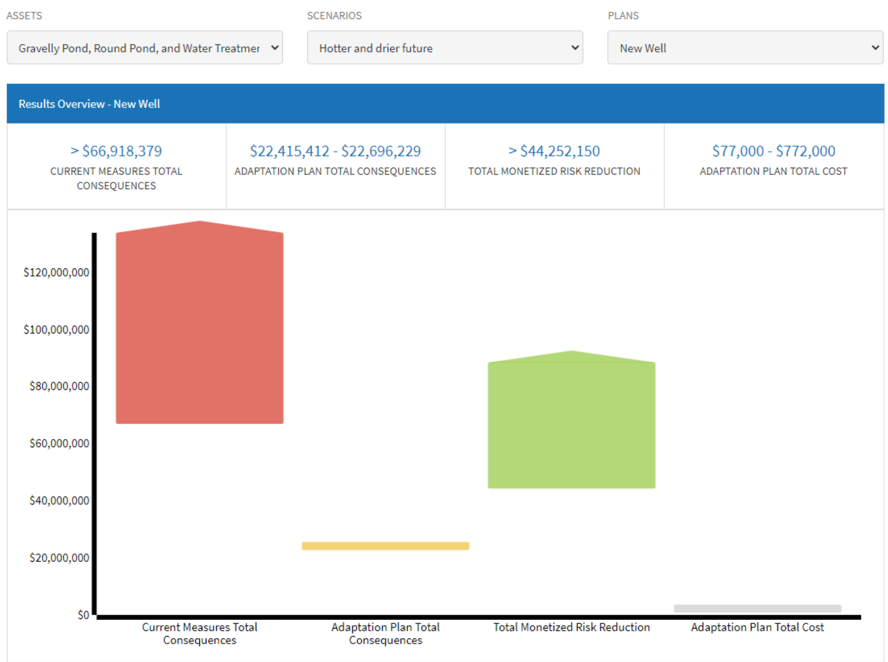


Figure 17 Risk Assessment. Gravelly Pond, Baseline Scenario, Watershed Protection

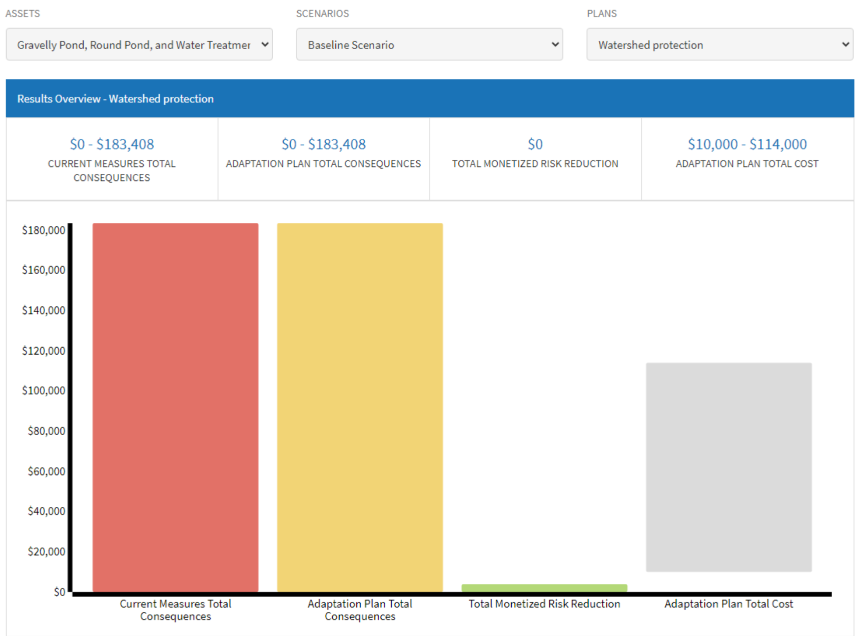
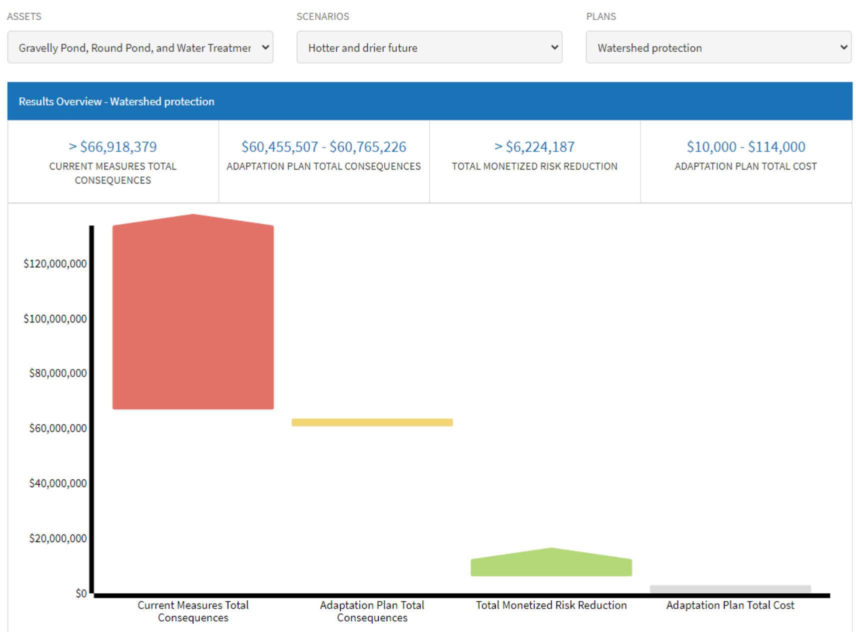


Figure 18 Risk Assessment. Gravelly Pond, Hotter and Drier Future Scenario, Watershed Protection



Likelihood Sensitivity

CREAT enables users to consider additional results of their analysis to support decision making, including how the likelihood of a climate change scenario occurring will impact the cost-effectiveness of implementing an Adaptation Plan. In CREAT, scenarios and threats are considered "conditional," where the likelihood is assumed to be 100%. **Figures 19-24** show how scenario likelihood can alter cost-effectiveness. These figures are based on a combined analysis of the utility and regional economic impacts.

The red "*Wait and See*" range represents the range in which the cost to implement the selected plan exceeds the entire range of possible risk reduction for the threats in the selected scenario. The orange "*Consider Implementing Plan*" range represents the range in which the cost to implement the selected plan overlaps with the range of possible risk reduction for the threats in this scenario. In this range, there would be an uncertain return on investment for implementing the adaptation options. For plans with significant orange ranges, users should consider additional benefits gained from implementing the adaptation options. Additional assessments with potential increases in risk reduction could support decision making on whether or not to implement the options.

A green "*Implement Plan*" range represents the range in which the costs to implement the selected plan are below the entire range of possible risk reduction for the threats in this scenario. In this range of likelihood, the Adaptation Plan is cost-effective to implement, since there would be a positive return on investment. The monetized risk reduction alone provides adequate benefit to support the decision to implement this plan. For example, the following Plans have monetized risk reduction benefits and a probable positive return on investment under almost any likelihood: Interconnections, New Wells, and Watershed Protection under a Hotter, Drier Future Scenario as well as Watershed Protection under a Baseline Scenario.

Figure 19 Likelihood Sensitivity, Interconnections, Baseline Scenario

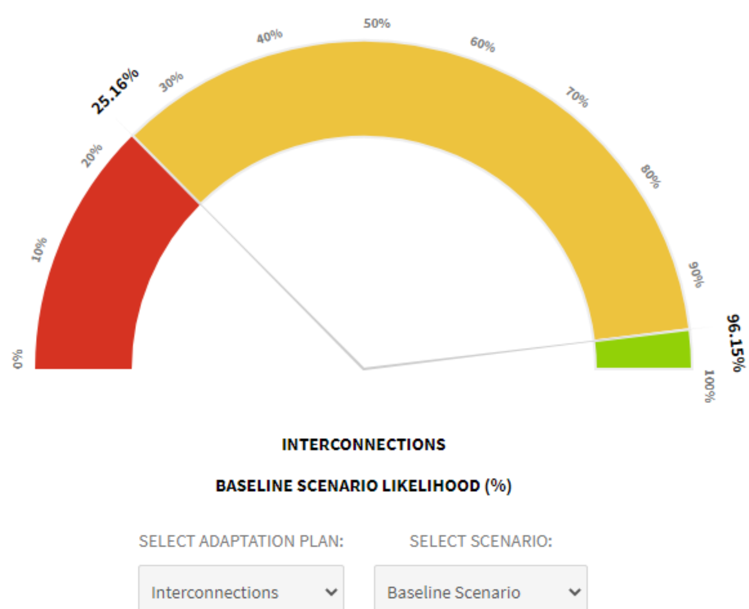


Figure 20 Likelihood Sensitivity, Interconnections, Hotter and Drier Future

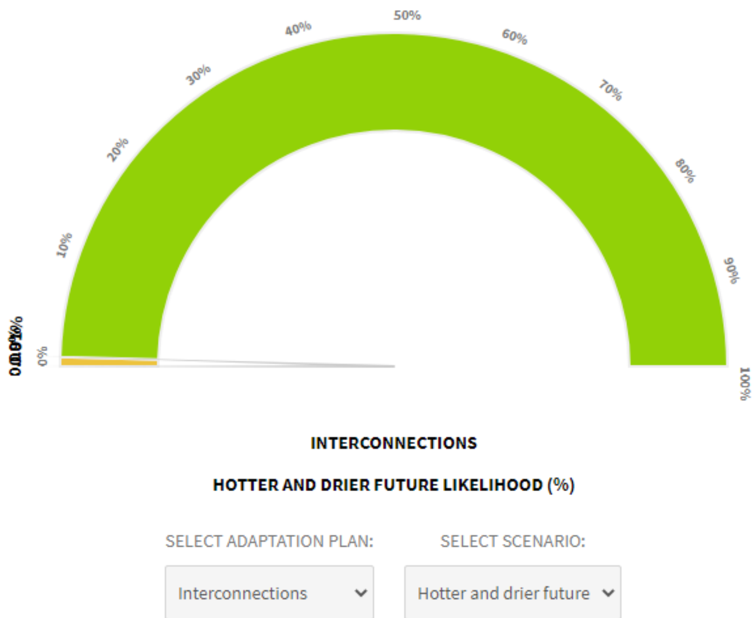


Figure 21 Likelihood Sensitivity, New Well, Baseline Scenario

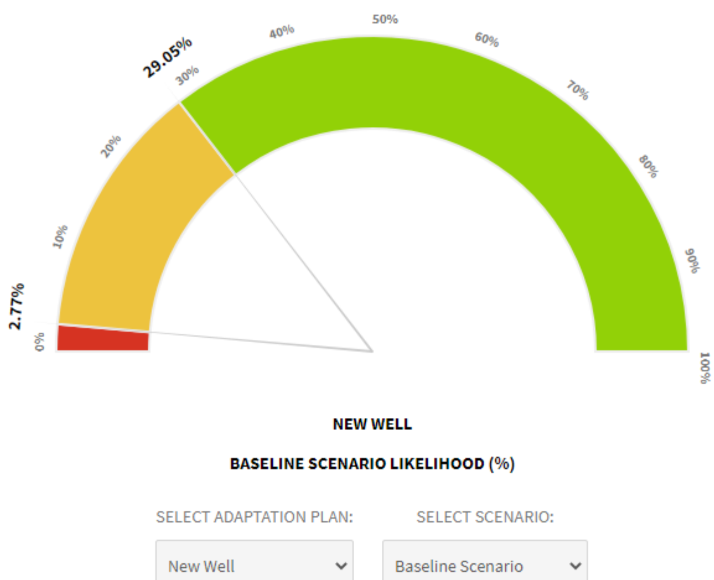


Figure 22 Likelihood Sensitivity, New Well, Hotter and Drier Future

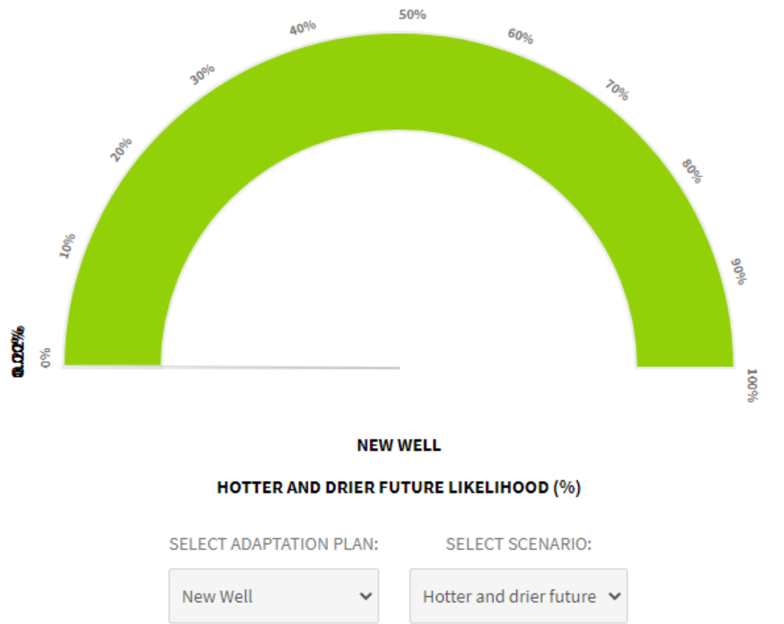


Figure 23 Likelihood Sensitivity, Watershed Protection, Baseline Scenario

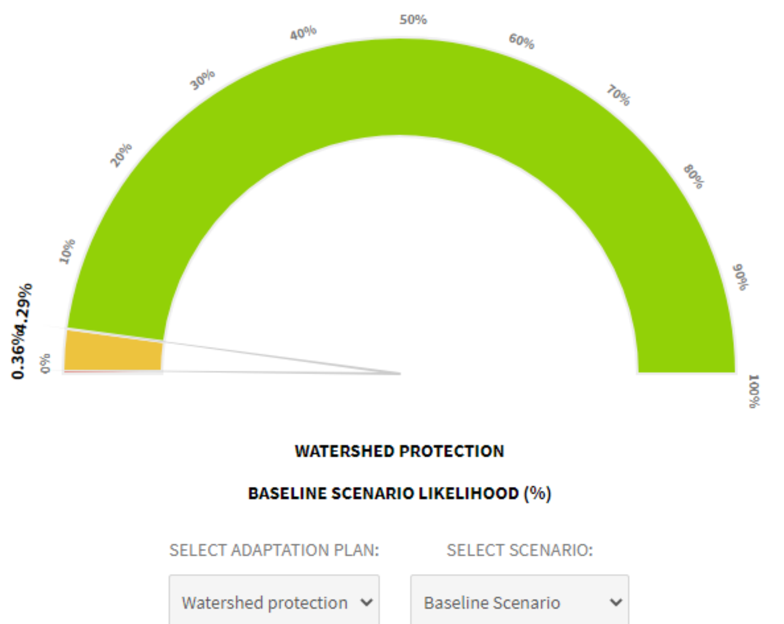
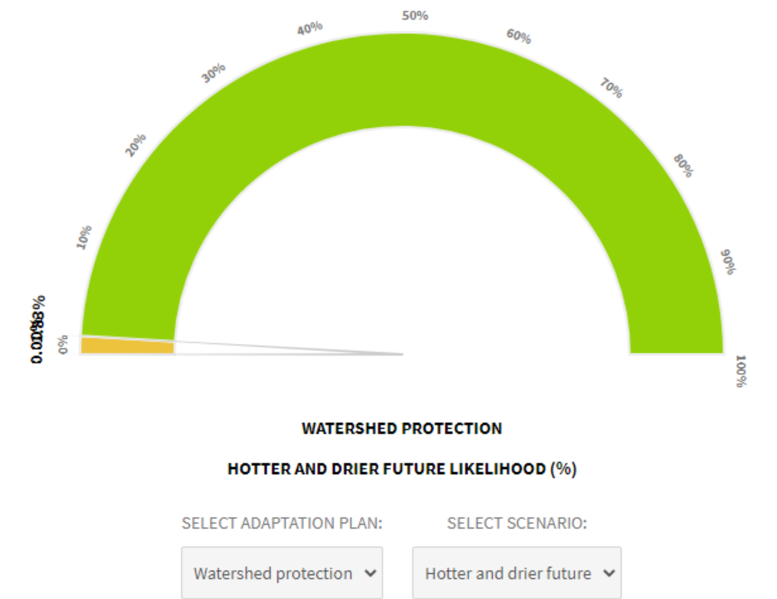


Figure 24 Likelihood Sensitivity, Watershed Protection, Hotter and Drier Future



While the cost-effectiveness of an Adaptation Plan is an important consideration for utility planning, some Adaptation Plans may provide additional benefits outside of the risk reduction the plan provides. Other metrics, such as energy savings, socio-economic benefits, community public health benefits, and source/receiving water benefits can be important factors to take into account when considering the implementation of Adaptation Plans. These non-monetized costs or benefits can help a utility understand the impact of adaptation outside of the utility's assets and operations. MBTS considered these qualitative impacts during this CREAT exercise, as shown in **Table 13.** Energy Impacts would be "Medium" and "Low" for the two Adaptation Plans related to adding capacity since there would be additional energy needs.

Table 13 Qualitative Impacts of Adaptation Plans

Plan	Energy Impacts	Socio-economic Impacts	Community Public Health Impact
Interconnections	Low	Low	Neutral
New Well	Neutral	Neutral	Neutral
Watershed Protection	Neutral	Beneficial/Energy Savings	Beneficial/Energy Savings

NEXT STEPS

This CREAT exercise was intended to demonstrate CREAT's functionality and capability, and to help continue to build MBTS's understanding of the tool. To improve the outcomes of the current demonstration assessment results, MBTS can revisit the entered data and assumptions made throughout the exercise and refine the data in each module. The Existing and Potential Adaptive Measures include customized definitions, and all Potential Adaptive Measures have cost estimates. While no further refinement is necessary at this time to complete the assessment, additional climate threats, adaptive measures, results, and studies can be explored.

Below are several options MBTS can take for future CREAT uses, as identified over the course of the exercise.

- Climate Threats. MBTS can conduct an analysis using flooding as the primary climate threat.
- Adaptive Measures. Other Potential Adaptive Measures may be included, such as demand reduction strategies or other measures that may be identified by the Task Force.

Results. MBTS could utilize results from the CREAT exercise to study the impacts of enacting these Adaptation Plans. In the future, MBTS could update consequence category costs as well as adaptive measure costs to consider projected changes in drought risk and/or evolving financial environments.

Studies. The Watershed Protection Adaptation Plan had a relatively higher cost than assessed benefit under a Hotter and Drier Future. Because the CREAT assessment did not attempt to capture the impacts from potential future land use change, there may be potential benefits to implementing the Plans that were not captured here.

APPENDIX A: EXERCISE PARTICIPANTS

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APPENDIX B: Models Used in Developing Climate Data

MODEL NAME	STORM SCALARS	SOURCE / INSTITUTION
ACCESS1_0		Australia, Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM)
ACCESS1-3	X	
BCC-CSM1_1		China, Beijing Climate Center, China Meteorological Administration
BCC_CSM1_1_M		
BNU_ESM		China, College of Global Change and Earth System Science, Beijing Normal University
CANESM2	X	Canada, Canadian Centre for Climate Modelling and Analysis
CCSM4	X	USA, National Center for Atmospheric Research (NCAR)
CESM1_BGC	X	USA, Community Earth System Model Contributors
CESM1_CAM5		
CMCC_CM	X	Italy, Centro Euro-Mediterraneo per i Cambiamenti Climatici
CMCC_CMS	X	
CNRM_CM5	X	France, Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique
CSIRO_Mk_3_6	X	Australia, Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence
EC_EARTH		EC-EARTH consortium
FGOALS_G2		China, LASC, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University
FGOALS_S2		China, LASC, Institute of Atmospheric Physics, Chinese Academy of Sciences
GFDL_CM3		USA, NOAA General Fluid Dynamics Lab
GFDL_ESM2G	X	
GFDL_ESM2M	X	
GISS_E2_H		USA, NASA Goddard Institute for Space Studies
GISS_E2_H_CC		
GISS_E2_R		
GISS_E2_R_CC		
HADGEM2_AO		Korea, National Institute of Meteorological research/Korea Meteorological Administration
HADGEM2_CC		UK, Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2_ES	X	
INMCM4	X	Russia, Institute for Numerical Mathematics
IPSL_CM5A_LR	X	France, Institute Pierre Simon Laplace
IPSL_CM5A_MR	X	
IPSL_CM5B_LR	X	
MIROC_ESM	X	Japan, Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC_ESM_CHEM	X	
MIROC5	X	
MPI_ESM_LR	X	Germany, Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)
MPI_ESM_MR	X	
MRI_CGCM3	X	Japan, Meteorological Research Institute
NorESM1_M	X	Norway, Norwegian Climate Center
NORESM1_ME		

APPENDIX C: METHODOLOGY FOR PROJECTED CLIMATE DATA IN CREAT[6]

The climate information available in CREAT provides a snapshot of how changes in climate might exacerbate current concerns. In addition to the national and international assessments synthesized in CREAT, historical observations and model projections are organized for users to review and select as part of their scenarios.

Historical Climate Conditions

CREAT provides historical climate data for temperature and precipitation to help users assess current risk as part of their Baseline Scenario. Average annual and monthly conditions are sourced from the Parameter-elevation Regressions on Independent Slopes Model[7] (PRISM) dataset based on observations from 1981 to 2010. Data available from the Climate Research Unit[8] are used in places where PRISM data were unavailable, such as in Alaska, Hawaii, and Puerto Rico. The resultant dataset covers all U.S. states and Puerto Rico at a 0.5-degree resolution in latitude and longitude.

Historical Extreme Events

Historical data on extreme events, including both temperature and precipitation, are based on time-series analysis of the data available from the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center climate stations[9]. Data for historical extreme precipitation events are representative of each station.

For intense precipitation events, time series of historical daily precipitation data from 11,010 stations were reviewed and converted into annual maxima time series for 24-hour and 72-hour precipitation. Any station with data available during 1981 through 2010 was included.

Historical hot days, those days with daily maximum temperature over 90, 95, and 100°F, were calculated using historical daily maximum temperature data from 8,150 stations. These stations were selected from the same stations used for intense precipitation based on a minimum of 95% completeness for April through October daily observations from at least one calendar year in the period of observation.

Historical Streamflow

Historical flow data in CREAT are from approximately 8,200 U.S. Geological Survey (USGS) stream gaging sites across the United States with daily discharge information covering the period of record[10]. The time-series data were compiled to provide annual flow metrics for each site, which were used to generate average daily flow and 7-day low flow data at each gage.

Coastal Data

CREAT provides projections of future flood frequency under various projected sea level rise scenarios to help users assess short-term and long-term risk of coastal flooding. Projected sea level rise and flooding scenarios are derived from models produced by NOAA and published in a series of two reports which report sea level rise scenarios and flood inundation frequency at select locations. For assessing risk of coastal flooding for current global mean sea level (GMSL), NOAA employed methods[11] to account for regional considerations, such as earth's gravitation field and rotation, shifts in

[6] Adapted from the CREAT 3.1 Methodology Guide, available at: **https://creat.epa.gov**.
[7] PRISM Climate Group, Oregon State University. Available online at: **http://www.prism.oregonstate.edu/**.
[8] Data set available at: **http://catalogue.ceda.ac.uk/uuid/2949a8a25b375c9e323c53f6b6cb2a3a**.
[9] For more information on NOAA climate stations, see: **http://www.ncdc.noaa.gov/data-access/land-based-station-data**.
[10] USGS, 2017. Surface-Water Daily Data for the Nation. U.S. Geological Survey, National Water Information System (NWIS). Available: https://waterdata.usgs.gov/nwis/dv/?referred_module=sw
[11] NOAA Technical Report NOS CO-OPS 083: Global and Regional Sea Level Rise Scenarios for the United States

oceanographic circulation, and vertical land movement (VLM), to produce relative sea level (RSL) to compare with calculated flooding thresholds at tide gauge locations. These thresholds were developed by NOAA to provide a national definition of coastal flooding and quantification of flood impacts.

Projected Climate Conditions

CREAT provides projected changes from Global Climate Models (GCMs) as available from the Coupled Model Intercomparison Project, Phase 5 (CMIP5)[12] which is the same data used to support the IPCC Fifth Assessment Report.[13] Data provided in CREAT were from model simulations employing Representative Concentration Pathway 8.5, a higher trajectory for projected greenhouse gas concentrations to support assessments looking at higher potential risk futures.

CREAT uses an ensemble-informed approach to derive meaningful choices from the results of 38 model runs[14] for each 0.5 by 0.5 degree location. This approach involves generating a scatter plot of normalized, projected changes in annual temperature and precipitation by 2060 for all models. Statistical targets were calculated based on the distribution of these model results and the five models closest to those targets were averaged to generate each projection (**Figure C-1**). The targets were designed to capture a majority of the range in model projections of changes in annual temperature and precipitation, as follows:

- Warmer and wetter future conditions: average of five individual models that are nearest to the 95th percentile of precipitation and 5th percentile of temperature projections;
- Moderate future conditions: average of five individual models that are nearest to the median (50th percentile) of both precipitation and temperature projections; and
- Hotter and drier future conditions: average of five individual models that are nearest to the 5th percentile of precipitation and 95th percentile of temperature projections.

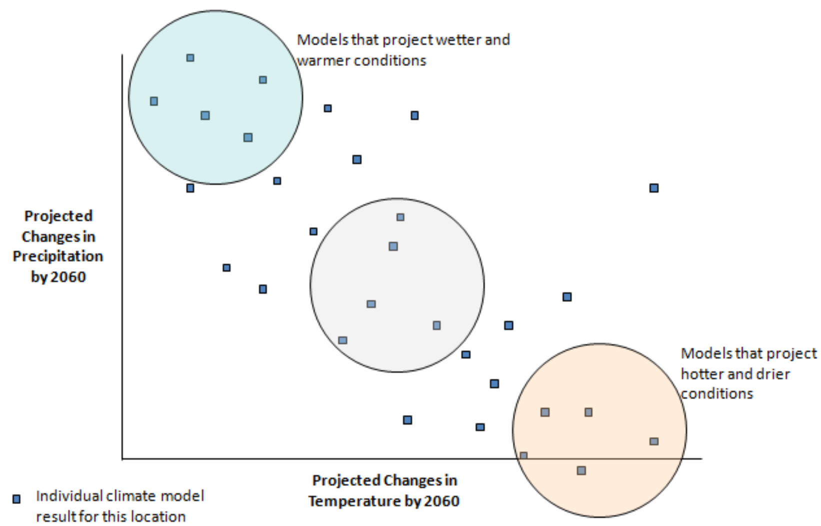

Figure C-1. Illustration of Ensemble-informed Selection of Model Projections to Define Potential Future Conditions

Once the models for each projection were selected, these models were ensemble-averaged to calculate annual and monthly changes for temperature and precipitation. CREAT selects the most appropriate data to match the defined planning horizon from two available data sets – one for 2035, which is based on projection data for 2025–2045, and one for 2060, which is based on projection data for 2050–2070. The selection of the appropriate CREAT-provided time period

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[12] World Climate Research Programme Coupled Model Intercomparison Project available at: **http://cmip-pcmdi.llnl.gov/cmip5/**.
[13] IPCC Fifth Assessment report available at: **https://www.ipcc.ch/report/ar5/**.
[14] List of models used in analyses provided in Appendix B: Models Used in Developing Climate Data

is based on the End Year defined by the user during the time period selection. If the End Year is 2049 or earlier, the 2035 data are selected; otherwise, CREAT selects the 2060 data set.

Projected Extreme Events

CREAT also provides projections of extreme heat in terms of the new total number of hot days following the projected shift in temperature. The projected changes in hot days were linked to the models selected for projected changes in average temperature and precipitation. The change in monthly average temperature for April through October for the analysis location was added to the daily time series from that station to generate a new time series for each projection. The number of hot days was then calculated using the same method employed for historical hot days to generate projected number of hot days.

Similar to the development of model projections of changes in average temperatures and precipitation, CREAT uses an ensemble-based approach to identify a range of possible changes in total storm precipitation (**Figure C--2**). A subset of the GCMs used earlier (22 of the 38 models) provide scalars or changes in precipitation per degree of warming, for storm events of the same return intervals as the historical storms provided in CREAT. Each model provides a different scalar for each return interval based on model-projected daily precipitation patterns.

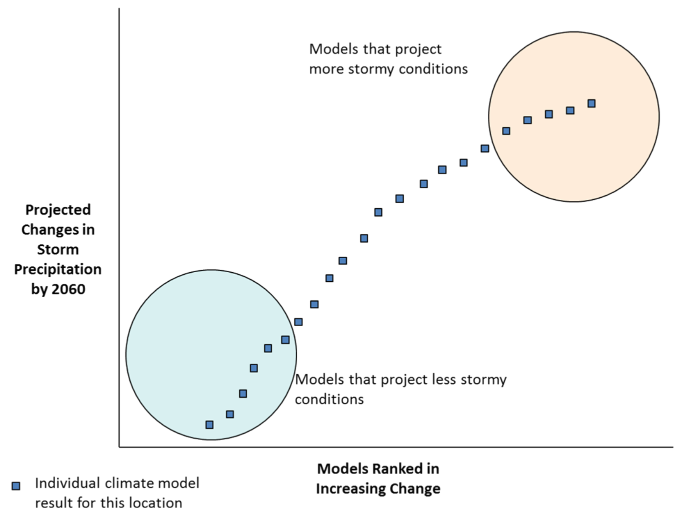

Figure C-2. Illustration of Ensemble-informed Selection of Model Projections to Define Potential Future Storm Conditions

The scalars from these models were ranked based on the scalars for the storm events with a 5-year return interval. The use of 5-year storm events to rank the models was based on the assumption that water sector utilities dealing with intense storm events are often more concerned with more frequent storm events. Ensembles of five models were selected as describing a “Stormy Future,” which are the highest models and a “Not as Stormy Future,” which are the lowest models. In each case, these models were averaged to provide two model projections available to users.

APPENDIX D: EXISTING AND POTENTIAL ADAPTIVE MEASURES

Table D-1. Existing Adaptive Measures

EXISTING ADAPTIVE MEASURE	DESCRIPTION	TOTAL COST[15]
Round Pond Well	Groundwater well adjacent to Round Pond used as recharge assistance for Gravelly Pond to address limited watershed recharge. Costs are electricity and chemicals needed to operate.	$0
Source Management	Shift to primarily use well during winter to allow for greater recharge of Gravelly Pond.	$0
Tiered Rate Structure	Tiered rates increase costs for greater use, promoting conservation.	$0
Water Loss Minimization	Reduce leakage from water distribution system. Saves energy and treatment chemicals costs. Detection and remediation of leakage provides opportunities to inspect and limit asset degradation. Pipe lining and replacement to reduce water loss. Replacement of water meters. Cost is per year.	$1,000,000
Water Use Restrictions	Develop schemes and rules for limiting service provisions when conditions are unfavorable for supply to meet demand. These plans should be devised based on customer expectations, current practices and regulations, and expected changes in climate conditions. Establishing authorizations to establish rates for rationing and working with research community to define conditions to trigger the program should be considered. Voluntary restrictions under moderate conditions; mandatory restrictions under more severe conditions. No enforcement capability.	$0

[15] For this column, "$0" may indicate either the cost was unknown, trivial, or occurred long ago.

Table D-2. Potential Adaptive Measures

POTENTIAL ADAPTIVE MEASURE	DESCRIPTION	ESTIMATED COST
Interconnections with Beverly	Intermunicipal agreement for wholesale water purchase from Beverly. Intended to supplement on an emergency or as-needed basis. Increase interconnection between systems for regional water networks. These connections may be used in water exchanges, trading or other collaborative arrangements that build resilience through providing alternative supplies or capabilities. Assumes Beverly has water to sell, but the regional impacts are not currently known. Estimated need for drought is 50MG/year. If Lincoln Street Well is unusable, could be .5MGD. Based on current (2022) commercial rates, $.014/gal.	$700,000 - $2,555,000
New Well	Develop redundant capabilities and options for water supply including water storage, water sources, treatment plants, intakes, and distribution system. Development or replacement could include entire facility or just critical portions to support operations when damage or loss occurs. Min cost assumes new well is on town-owned land, close to current system. Max cost is new well in distant location, land needs to be acquired. Assume 20 years at 3%, 1% annual O&M.	$77,000 - $772,000
Watershed Protection	Acquire land for expansion or natural resource management. The identification and acquisition of land may include purchases, leasing or trading or mergers of systems. Use for land may include new facilities, ecosystems for water resource protection, terrestrial sequestration, or future development of water resource on land. Two-part focus: acquisition of land around Gravelly Pond, predominantly in Hamilton and Wenham, some in Manchester, and expansion of source water protection overlay. Max cost assumes $167,000/ac, 10 acres, financed 20 years at 3%. cost is admin costs associated with expansion of overlay district.	$10,000 - $114,000

APPENDIX E: CONSEQUENCE ASSUMPTIONS

The assumptions that MBTS made while selecting the economic consequence levels for each asset (Gravelly Pond and the Lincoln Street Well) for the given climate scenarios (Baseline Scenario and Hotter, Drier Future Scenario) under each Adaptation Plan (Current Measures, Interconnections, and New Well, and Watershed Protection) are organized here.

MBTS chose to include Regional Economic Consequences in their assessment. Regional Economic Consequences were calculated by CREAT using the utility's population served, State population, and other economic data from the U.S. Economic Census, business resilience factors of industries served by the water or wastewater system, the number of days the disruption lasts, and the percentage reduction of customer water use. Under a Baseline Scenario, MBTS selected "$0" for the Regional Economic Consequences for all asset/threat pairs except Lincoln Street Well and drought, which was calculated to have total Regional Economic Consequences of $2,657,361. Under a Hotter, Drier Future CREAT calculated Regional Economic Consequences for all asset/threat pairs; $28,471,722 for Lincoln Street Well and drought, $277,124,758 for Lincoln Street Well and Water Quality Degradation, $56,943,444 for Gravelly Pond and drought, and $9,490,574 for Gravelly Pond and Water Quality Degradation.

The selection of the economic consequence levels relied on the assumptions below. The assumptions are outlined for each asset under the Current Measures and the applicable Adaptation Plan. MBTS completed the Gravelly Pond/Drought and the Lincoln Street Well/Water Quality Degradation asset/threat pairings with EPA and completed the Gravelly Pond/Water Quality Degradation and Lincoln Street Well/Drought pairings on their own. The assumptions MBTS made for the asset/threat pairings completed with EPA are described below for the following categories: Utility Business Impacts, Utility Equipment Damage, Environmental Impacts, Source/Receiving Water Impacts, Duration of Service Outage, and Percent of Customers without Service.

Asset/Threat: Gravelly Pond/Drought

Plan: Current Measures

- Baseline Scenario
  - Utility Business Impacts: MBTS chose low, they have endured recent periods of flash drought without significant business impacts.
  - Utility Equipment Damage: MBTS chose low, as the severity of historical droughts have not significantly damaged equipment.
  - Environmental Impacts: MBTS chose low because recent droughts have not been severe enough to drive environmental impact costs.
  - Source/Receiving Water Impacts: MBTS chose low because recent droughts have not been severe enough to significantly impact the source/receiving waters.
  - Duration of Service Outage: MBTS chose 0 days of outage because historical droughts have not resulted in service outage.
  - Percent of Customers Without Service: MBTS chose 0% because historical droughts have not risen to the level that customers are without service.
- Hotter drier
  - Utility Business Impacts: MBTS chose high because declared drought and water use restrictions would impact revenue generated from their tiered-rate system.
  - Utility Equipment Damage: MBTS chose low because in the event of low water levels that could result in equipment damage, they would not be using that equipment.
  - Environmental Impacts: MBTS chose medium because drawing water from lower levels in Gravelly Pond and Lincoln Street Well could result in a need for additional treatment procedures.

- Source/Receiving Water Impacts: MBTS chose high because treatment costs could increase if water had to be drawn from lower levels during drought, and there is also potential for algal blooms in Gravelly Pond in a hotter future.
- Duration of Service Outage: Chose 100 days because this best represents an extended summer season that is typically when drought conditions develop and persist.
- Percent of Customers Without Service: MBTS chose 30% because they estimated that in the event of declared drought, they would be enacting water use restrictions, estimated to limit provision of water by about 30%.

Plan: Interconnections

- Baseline Scenario: Unchanged
- Hotter, Drier
    - Utility Business Impacts: MBTS chose low because the additional cost of purchasing water from Beverly would be reflected in the cost to customers, and the difference would be made up.
    - Utility Equipment Damage: MBTS chose low because utilizing Interconnections would not result in any additional equipment impacts.
    - Environmental Impacts: MBTS chose medium because MBTS is likely unable to purchase enough water from Beverly to offset costs associated with addressing potential environmental impacts of hotter future in Gravelly Pond.
    - Source/Receiving Water Impacts: MBTS chose medium because Gravelly Pond will still be impacted by drought conditions.
    - Duration of Service Outage: MBTS chose 100 days because this best represents an extended summer season that is typically when drought conditions develop and persist.
    - Percent of Customers Without Service: MBTS chose 10% because utilizing Interconnections with Beverly would not fully meet the difference in supply.

Plan: New Well

- Baseline Scenario: Same
- Hotter drier
    - Utility Business Impacts: MBTS chose low because a new well would be intended to completely offset the loss of Gravelly Pond
    - Utility Equipment Damage: MBTS chose low because utilizing a new well would not have significant equipment impacts.
    - Environmental Impacts: MBTS chose low because a utilizing a new well might offset some of the environmental impacts of drought on Gravelly Pond, but would not significantly change the conditions at the Pond.
    - Source/Receiving Water Impacts: MBTS chose medium because a new well would not stop Gravelly Pond from being impacted by drought.
    - Duration of Service Outage: MBTS chose 100 days because this best represents an extended summer season that is typically when drought conditions develop and persist.
    - Percent of Customers Without Service: MBTS chose 10% because in a declared drought MBTS would be enacting water use restrictions even with a new well.

Plan: Watershed Protection

- Baseline Scenario: Same
- Hotter drier

    - Utility Business Impacts: MBTS chose high because watershed protection would not alleviate drought conditions; business would still be impacted.
    - Utility Equipment Damage: Chose low because equipment will not be used if water levels are low enough to damage the equipment.
    - Environmental Impacts: Chose low because watershed protection actions could mitigate some of the impacts of the drought threat to Gravelly Pond, but not greatly.
    - Source/Receiving Water Impacts: MBTS chose medium because watershed protection actions would likely not significantly change the impacts of drought on the source.
    - Duration of Service Outage: MBTS chose 100 days because this best represents an extended summer season that is typically when drought conditions develop and persist.
    - Percent of Customers Without Service: MBTS chose 30% because they estimated that in the event of declared drought, they would be enacting water use restrictions estimated to limit provision of water by about 30%.

Asset/Threat: Lincoln Street Well/Water Quality Degradation

Plan: Current Measures

- Baseline Scenario: MBTS chose low for all categories, 0 days of service outage, and 0% of customers without service because they have not had saltwater intrusion impact their operations.
- Hotter drier: MBTS chose very high for all categories, 365 days of service outage, and 40% of customers without service (the percentage of MBTS's water supplied by the well) assuming saltwater intrusion into the aquifer that feeds the Lincoln Street Well. This would result in the total loss of the asset and would have significant costs.

Plan: Interconnections

- Baseline Scenario: No change from current measures.
- Hotter, Drier
    - Utility Business Impacts: MBTS chose medium because the additional cost of purchasing water from Beverly would be reflected in the cost to customers, and the difference would be partially made up.
    - Equipment Damage: MBTS chose medium to reflect the cost of using different equipment, Lincoln Street equipment would not be in use.
    - Environmental Impacts: MBTS chose medium because utilizing interconnections might mitigate some of the environmental costs, but there remains a possibility that there will be costs associated with maintaining regulatory compliance.
    - Source/Receiving Water Impacts: MBTS chose low because Lincoln Street Well will not be in use.
    - Duration of Service Outage: MBTS chose 365 because the loss of Lincoln Street Well would impact operations year-round.
    - Percent of Customers Without Service: MBTS chose 10% to reflect water use restrictions in the event of the loss of Lincoln Street Well.

Plan: New Well

- Baseline Scenario: No change from current measures.
- Hotter drier: MBTS chose low for all categories, 0 days for duration of service outage, and 0% of customers without service because the cost of establishing a new well is reflected elsewhere in the CREAT exercise, and the utilization of a new well would offset the loss of Lincoln Street Well.

Plan: Watershed Protection

- Baseline Scenario: No change from current measures.

- Hotter drier: MBTS chose very high for all categories, 365 days for duration of service outage, and 40% of customers without service because watershed protection would not impact the loss of Lincoln Street Well to saltwater intrusion.

APPENDIX F: CLIMATE TOOLS

Name of Resource	Primary Threat	Description	Link
Drought.gov Home Page	Drought	NOAA's National Integrated Drought Information System (NDIS) homepage where resources, publications, data, and various tools are available regarding drought.	Link
Flash Drought	Drought	Webpage explaining the concept of Flash Drought (7-10 day absences of rain that come and go quickly), which commonly affects the Northeast.	Link
Historic Drought - Essex County	Drought	Monthly and Weekly data showcasing the historical drought conditions of Essex County, MA via precipitation index.	Link
Outlooks and Forecasts	Drought	Webpage showing the current/upcoming forecasts and outlooks of precipitation and drought conditions across the country.	Link
Drought Status - Northeast	Drought	Webpage denoting current drought status updates for the Northeast when they are available.	Link
Drought Management Taskforce	Drought	Webpage with various resources of the Drought Management Task Force (DMTF) for the state of MA including information on the status, management, monitoring, and response to drought conditions.	Link
Drought Termination and Amelioration	Drought	A tool developed by NOAA that identifies how much precipitation is required to end a drought as well as the probability that a region may receive that necessary amount of precipitation. Users can generate maps to show probability or the amount of precipitation to ameliorate or end a drought at different monthly scales.	Link
Northeast DEWS Dashboard	Drought	Webpage that provides weekly graphical updates of drought across the Northeast from the Northeast Regional Climate Center. Streamflow and groundwater levels, soil moisture, precipitation, evaporation demand are among the included variables researched.	Link
Northeast Regional Climate Center	Drought	Home page for the Northeast Regional Climate Center that compiles data, tools, and resources for various climate research on climate change's effect on the Northeast.	Link
2022 Sea Level Rise Technical Report	Sea Level Rise	A technical report with the most up-to-date projections of sea level rise through the year 2150 which provides communities the ability to assess potential changes in average tide heights and height-specific threshold frequencies to adapt to sea level rise.	Link

Adapting Stormwater Management for Coastal Floods	Sea Level Rise	A tool developed by NOAA to help understand, assess, analyze, and take action against the impacts of coastal flooding. Localized information is used to show the impact of flooding and can improve planning efforts to combat sea level rise.	Link
NOAA Sea Level Rise Viewer	Sea Level Rise	A tool developed by NOAA to view the effect of sea level rise on individual communities by utilizing analytical methods and predictive models. Adjust the anticipated sea level rise bar to anticipate inundation and flood risk in your community.	Link
Coastal Flood Exposure Mapper	Sea Level Rise	A tool developed by NOAA that aims to predict the severity coastal flooding on areas effected by high tide events, increased storms, sea level rise, or storm surge. All of these factors can be layered into a map that creates a composite, holistic outlook of how these factors will impact coastal flooding in local communities.	Link
ResilientMA Climate Map	Several Climate Threats	A tool developed by the Resilient MA Climate Change Clearinghouse that allows users to interactively explore data and create maps related to climate change impacts, vulnerability, and adaptation across Massachusetts. The library of viewable map layers and interactive map functions has been developed by recommendations from state experts in climate change.	Link