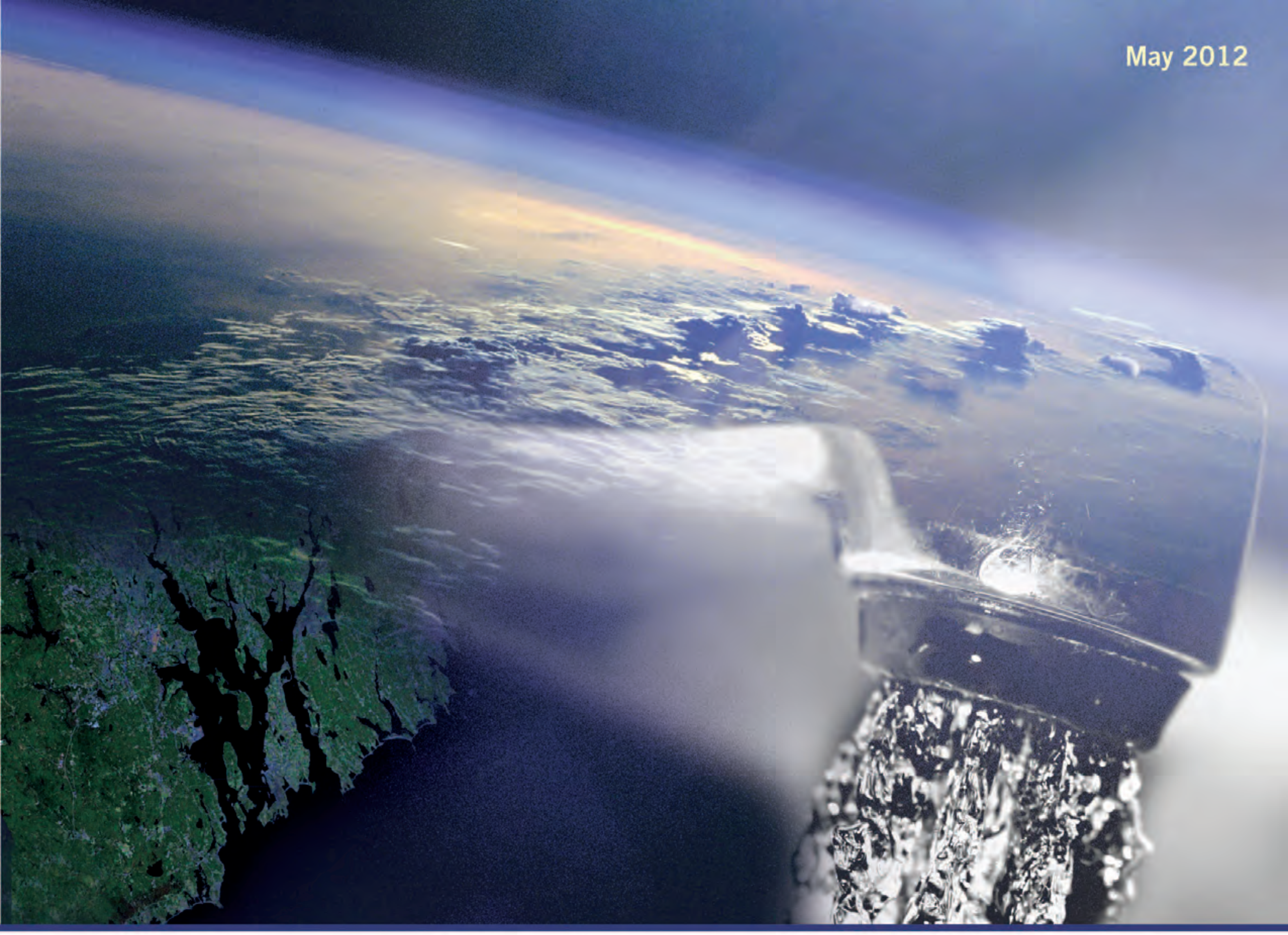

May 2012

SafeWater RI

ENSURING SAFE WATER FOR RHODE ISLAND'S FUTURE

Phase 1 Report

Prepared for:

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TETRA TECH

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1.0 BACKGROUND AND OVERVIEW

Drinking water utilities in Rhode Island face numerous challenges such as drought, pollution, competing water uses, and aging infrastructure that must be addressed to ensure that their customers receive safe, dependable drinking water. The impacts from global climate change will exacerbate current challenges and present new risks to Rhode Island water utilities and their service areas.

Altered precipitation patterns could increase flood events, like the recent flooding experienced in 2010, while more extreme weather events will pose storm surge risks to the state's more than 400 miles of coastlines. In addition to physical damage to water infrastructure systems and dams, flooding can also increase turbidity and pollutant loads in source water, requiring more extensive treatment to remove the pollutants. Excessive flooding can also release pathogens from storm sewer systems when their capacity is exceeded to manage wastewater during storm events. Areas that rely heavily on wells, such as the eastern portion of the state, could potentially become contaminated by surface water containing pathogenic protozoa such as *Giardia* and Cryptosporidium. Additionally, the global melting of glaciers and ice sheets will impact coastal areas through sea-level rise. The elevated sea-levels can contaminate aquifers through intrusion of saltwater and damage coastal ecosystems, which will be particularly challenging for Rhode Island since the majority of the population lives along the coastline.

In January 2012 the Rhode Island Department of Health (HEALTH), Office of Drinking Water Quality, launched *Safe***Water** RI*: Ensuring Safe Water for Rhode Island's Future (Safe***Water** RI*)* which is being led by Tetra Tech Inc. The project will help address the implications of climate change to drinking water utilities by providing locally relevant and actionable data for water utility managers to evaluate and plan for future scenarios. The objective of the project is to assess changing environmental conditions (including temperature, precipitation patterns, sea-level rise, and storm surge) and their potential impacts on drinking water utilities in Rhode Island, and develop strategies to address these changing conditions. The *Safe***Water** RI project includes four project components:

- Phase 1: Data Collection
- Phase 2: Assessment of Impacts
- Phase 3: Development of Management Strategies
- Phase 4: Outreach and Education

This report provides a summary of the methodology and findings of the first phase of the *Safe***Water** RI project. Phase 1 data collection activities included both primary data collection and a desktop literature review. The information presented in this report will inform the remaining *Safe***Water** RI project phases and is intended to present HEALTH with a summary of project activities and findings to date.

2.0 PRIMARY DATA COLLECTION

Tetra Tech collected primary data using 1) a survey that was distributed to the principal drinking water utilities and 2) consultation sessions that were held with Rhode Island government partners and drinking water utility representatives.

2.1 Survey

2.1.1 Methodology

A survey was developed to obtain information from water utility representatives and to initiate engagement with the water utilities at the project launch. The survey was designed to collect the following information:

- Current and future concerns of the water utility
- Planning tools and horizons used by the water utility
- Methods the water utility uses to address uncertainty associated with future planning
- Perceptions of the term climate change with various stakeholders

The survey used a mixed-methods approach so that quantitative data could be generated through multiple choice and priority ranking questions, while qualitative data could be obtained through open-ended questions. Survey Monkey was used for survey development and distribution. HEALTH identified a primary point of contact from each of the 25 largest water utilities in the state and distributed the initial survey request via email. The contacts were also encouraged to distribute the survey to others in their water utility that could complete the survey (targeted positions for survey completion included General Manager, Chief Engineer, Operator, Superintendent). The initial survey request was sent in February 2012 and responses were collected through March 2012. Appendix A includes the survey questions as they were presented to the drinking water utility representatives via Survey Monkey.

2.1.2 Key Findings

Survey responses were received from 23 drinking water utilities, with 26 total responses recorded.[1] Appendix B contains a complete listing of individuals that completed the survey.

Tetra Tech presented the initial survey results at the kickoff meeting with drinking water utility representatives (described in Section 2.3). The PowerPoint presentation is included as Appendix C.[2] Graphical and numerical summaries are provided for quantitative question responses, while qualitative question responses have been included in full or grouped where appropriate. Key findings from the survey include the following:

- Primary concerns for drinking water utilities include protection of public health, financial challenges, water quality protection, aging infrastructure, and regulatory restrictions. These concerns are similar for both short- and long-term planning horizons.
- Drinking water utilities use several strategies and techniques to manage their current water quality, water availability, and infrastructure needs. Most drinking water utilities employ a combination of approaches such as aggressive water quality monitoring, demand management, preparation of assessment and planning reports, and maintenance and replacement of aging infrastructure.
- The vast majority of drinking water utilities are encumbered by economic concerns in addressing their priority needs.
- Very few utilities use decision-support tools to assess future risk and demand.
- Most responders noted that they are "somewhat concerned" with the potential impacts of climate change but in many cases "don't know" how climate change impacts would affect their utilities.

[1] Multiple surveys were received from the following utilities: Portsmouth Water & Fire District (3 responses) and Naval Station Newport (2 responses).

[2] The PowerPoint presentation in Appendix C includes additional survey results that were received after the kickoff meeting.

- In addressing the impacts of weather-related events, respondents noted that water board members are the most proactive stakeholders, and customers and elected officials are generally viewed as reactive stakeholders.

The key findings highlight that although drinking water utilities are somewhat concerned with the potential impacts of climate change, they are not currently factoring climate change into their planning efforts. Responses suggest that water utilities do not have the necessary financial resources, decision-support tools or site-specific data to effectively evaluate how climate change might impact their utility and to plan for future scenarios.

2.2 Consultation with Rhode Island Government Partners

Consultative sessions were held with the Water Resource Board and Department of Environmental Management Office of Water Resources representatives. Separate consultative sessions were organized with each of the agencies by HEALTH and held on February 28, 2012. The objectives of the consultations were to: 1) introduce the project and objectives to the agencies; 2) solicit useful data or other resources that could inform the project; and 3) encourage the continued collaboration of these agencies throughout the life of the project. Several relevant resources were identified through these consultations and are included in Appendix D (listed under Rhode Island Government Resources).

2.3 Consultation with Rhode Island Drinking Water Utilities

A project kickoff meeting was held with representatives of the major drinking water utilities on February 29, 2012. Nine utilities participated: Bristol County Water Authority, East Smithfield Water District, Harrisville Fire District Water Department, Jamestown Water Department, Johnston Water Control Facility, Naval Station Newport (2 representatives), Portsmouth Water & Fire District (2 representatives), Town of North Kingstown, and the University of Rhode Island. A complete listing of individuals that attended the kick-off meeting is included in Appendix B.

2.3.1 Meeting Objectives and Design

The overall objective of the consultation was to solicit input from the drinking water utilities at the beginning of the project and to ensure that the project design and scope is optimal in addressing the drinking water utility needs. Early and continued engagement with the drinking water utilities will facilitate the implementation of adaptation options and stakeholder communication strategies to be developed later in the project.

The primary components of the consultation included: 1) outlining the objectives and process of the *Safe* **Water** RI project; 2) presentation of the survey results; and 3) a facilitated discussion with the utility representatives.

2.3.2 Key Findings

The purpose of the facilitated discussion was to solicit input from drinking water utilities to inform the scope and priorities of the *Safe***Water** RI project. The questions that were posed to participants include the following:

- Are there additional concerns that your drinking water utility faces that were not captured in the survey results?
- Are there current policies or regulations that would help your utility in meeting critical needs and priorities?
- Are there current policies or regulations that hinder your utility in meeting needs and priorities?
- What planning horizons do your utility use?

- What are the types of obstacles that your utility faces in operating your facility?
- What type of outreach do you currently conduct with your stakeholders? What additional outreach would you like to conduct with your stakeholders?
- How concerned are you about the impacts of climate change to your utility? How is the term climate change perceived by your stakeholders?

Primary Concerns

It was noted that consideration of both the geographic location of the utility and the water source is important in understanding the different concerns of each utility. Much of the drinking water in the central and southern parts of the state is drawn from groundwater aquifers. Surface water sources supplies the needs of the rest of the state, particularly in the northwest section.

Many of the participants identified drought as a concern. However, several of the utilities purchase their water from other utilities, such as from the Pawtucket and Providence Water Supply Board, and are not subjected to withdrawal/purchase limitations. Thus, potential water scarcity from drought is not a primary concern for those utilities. It was noted that the state is currently studying safe and sustainable withdrawal rates. If withdrawal restrictions are determined as a result of this study, then utilities would be forced to address the issue more aggressively. It was also noted by several participants that identifying an effective means of selling or shipping water from the northern to southern parts of the state could assist in meeting emergency water needs. The Portsmouth Water and Fire District cited their agreement to buy water on an emergency basis as a potential model for other utilities. Participants also identified regionalization[3] as an applicable issue for several areas and utilities in the state, and one that should be explored in more detail to assist with water sharing.

The majority of Rhode Island's population and several of the principal drinking water utilities are located in proximity to the coastal zone. While sea-level rise was identified as a potential concern, participants cited a lack of definitive data to indicate the extent of encroachment of future sea-levels on coastal resources. The lack of data makes it impossible to plan for sea-level rise in any meaningful way.

Water quality was identified as an area that is becoming more of a priority issue due to SEA-LEVELEPA water quality mandates and the inclusion of additional contaminants. Utilities are investing in water infrastructure that may not be able to handle the treatment necessary for new contaminants. Detecting additional contaminants could also increase the overall cost of service.

Many water utilities are struggling with changing water demand and the resultant revenue fluxes. For example, East Smithfield operates a small system in a town with a large elderly population, many of which live on a fixed income. Over the past two decades the mills that were once the economic engine of the town left—leaving an aging and outdated water supply infrastructure. East Smithfield now sells only half of the amount of water that was once sold in the 1980s and 90s, and has been forced to raise water rates significantly over the past five years. Conversely, Johnston Water Control Facility is seeing an increase in water demand as industry moves into their town over the next few years.

Useful Regulations or Policies

Water supply plans are now required to include a drought component. These plans are due for each utility in the July/August timeframe, which should help the utilities in planning for drought events.

The Water Resource Board developed a grass water policy with the landscapers association as a demand-side strategy to reduce water consumption, which was in general cited as a positive policy. However,

[3] For the purposes of this Report, regionalization is defined as the combination of services and cooperation among neighboring water systems to improve service and efficiencies, and to lower costs.

participants said that the policy has seen only limited response to date. North Kingstown noted that during a drought in the 1970's they instituted a watering policy using odd/even day allocations. An increase in water usage was actually recorded during that time-period. There was the sense from the public that "it's my day and so I need to water my lawn". Participants expressed that as Rhode Island shifts from primarily an industrial state to a residential state, water demand becomes less predictable. For example, there is a typical seasonal demand shift from winter to summer; however, the economic downturn has impacted the amount of water used as people struggle to pay their bills.

Challenging Regulations or Policies

The participants identified demand-side water reduction strategies as a "double-edged sword". If customers conserve water, then the utility sells less water, and is thus less able to meet financial obligations and sufficiently maintain infrastructure.

The requirement of the 2009 Water Use and Efficiency Act for utilities to establish revenue stabilization accounts and debt service reserves was identified as a challenge. Several participants said that they are not in a position to create the fund. They felt that their customers have been experiencing rate increases over the years and that obtaining approval to raise rates in the future will be difficult.

Johnston Water Control Facility noted that they are under a local government mandate to create a sewer utility, however the utility will not be funded at the amount it will take to develop and operate system.

Planning Horizons

Participants noted that they develop a 20-year comprehensive planning document that is updated every 5 years. The 20- and 5-year planning horizons are the most commonly used planning horizons for Rhode Island drinking water utilities.

Obstacles to Planning and Implementation

The participants underscored the survey results, in that economic constraints are the primary obstacles faced by drinking water utilities. One participant described the issue of rate increases for their utility as "trying to get blood from a turnip"—their utilities have raised rates all they can in trying to maintain aging infrastructure with decreased demand.

Many participants also noted that their utilities are small with limited staff, thus, there are technical and administrative barriers to implementing current and planned projects. For example, utilities don't always have the needed expertise to perform tasks in-house and there are staffing shortages if staff are sick or on vacation. East Smithfield Water District, Johnston Water Control Facility, and Harrisville Fire District Water Department each acknowledged that they had approached other utilities to share technical skills, and potentially merge and form larger utilities.

Outreach

Several utilities identified existing outreach efforts to their customers. The Portsmouth Water & Fire District televises all board meetings, and the Harrisville Fire District Water Department informs customers with changes and news via mailings. The Providence Water Board was cited as more proactively engaging with their customers and having resources for public outreach. Participants suggested that the utilities did not have the time/resources to develop and implement public outreach efforts but acknowledged these materials would be useful.

Several participants noted that water is severely underpriced and that a united message in pricing water, perhaps coming from the Rhode Island Water Works Association, would assist to stress how undervalued water is compared to other services. Participants also commented that public outreach and education efforts on the issue of aging infrastructure and increased maintenance costs, as well as seasonal demand issues (i.e., summertime water usage rates) could be beneficial.

Climate Change

There was a general agreement that climate change is a 'charged' term. There is a perception among drinking water utility stakeholders that the science is unsettled on whether climate change is actually occurring and whether man-made greenhouse gas emissions are causing climate change. Use of the terms 'extreme weather events' or 'severe weather' was recognized as potential substitute terms, particularly with water board members.

Participants also agreed that there are many immediate, pressing needs that water utilities are struggling with so that climate change is not viewed as a priority issue.

3.0 DESKTOP LITERATURE REVIEW

Tetra Tech conducted a desktop literature review to research the following issues: 1) the state of knowledge regarding climate change trends for the Northeast and specifically Rhode Island; 2) potential climate change impacts on drinking water utilities; and 3) best practices used in adaptation strategies for drinking water utilities. Resources were compiled through desktop research and consultations as part of the *Safe***Water** RI project and are listed in Appendix D.[4] The list is not intended to be exhaustive or complete, but the resources included are considered the most relevant/illustrative secondary information sources.

The literature review resources in Appendix D are organized into five sections:

- **Climate Trends.** Resources that include pertinent information on observed and/or projected climate trends.
- **Rhode Island Government Resources**. Relevant government resources and authorities for the *Safe***Water** RI project. These resources will be used to ensure regulatory compliance with proposed adaptation options and identify planning synergies associated with the *Safe***Water** RI project.[5]
- **Rhode Island: Additional Climate Resources**. A listing of climate resources that have been developed by coalitions and associations for the state.
- **Understanding and Managing Climate Risk.** Representative information on how municipalities and communities have approached climate risk management, including the role of state and local government action.
- **Water Utilities: Climate Change Vulnerability Assessment and Adaptation Planning.** A listing of resources that specifically address climate vulnerability assessment and best practices in adaptation for drinking water utilities.

Highlights from the literature review are presented in the sections below.

[4] All resources listed in the literature review are available for download and review on the *Safe***Water** RI ftp site: ftp://rhode_island/array1/RICC/. (Note: Copy and paste into windows explorer to open the link.)

[5] Note that resources that directly or indirectly inform climate change and water resources are included and is in no way exhaustive of relevant Rhode Island Government resources.

3.1 Climate Change Trends in the Northeast United States and Rhode Island

The following publications were found to have the most comprehensive and informative summaries of historic and projected future climate trends relevant to Rhode Island and New England:

- (Rhode Island) Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007b. *Rhode Island Report*, in Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Cambridge, MA, Union of Concerned Scientists (UCS).
- (Rhode Island) Heffner, L., R. Williams, V. Lee, P. Rubinoff, C. Lord. 2012. *Climate Change and Rhode Island's Coasts: Past, Present, and Future*. URI Coastal Resources Center and Rhode Island Sea Grant, Providence, Rhode Island.
- (Rhode Island) Roberts, T., Birky, K., Damm, K., Fisher, N., Hojagyedliyev, D., Knee, J., Marciante, L., Marshall, C., Mattison, C., McCracken, C., Mersha, S., Pagan, J., and Poyar, K. 2010. *Summary: Preliminary assessment of Rhode Island's vulnerability to climate change and its options for adaptation action*. Brown University Center for Environmental Studies, Graduate Seminar on Special Topics in Environmental Studies: Urban Adaptation to Climate Change. Available online at: http://envstudies.brown.edu/Summary-RIClimateChangeAdaptation.pdf.
- (Northeast) Union of Concerned Scientists (UCS). 2006. *Climate Change in the U.S. Northeast - A Report of the Northeast Climate Impacts Assessment*. Available online at: http://www.ucsusa.org/assets/documents/global_warming/necia_climate_report_final.pdf.
- (Northeast/United States) U.S. Global Change Research Program. 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press, Cambridge, MA.
- (Global) Intergovernmental Panel on Climate Change (IPCC). 2007: Climate Change 2007: Synthesis Report. Available online at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

There is a growing body of scientific research that is documenting the impacts of climate change in the region. In Rhode Island, research shows that spring is arriving earlier, summers are growing hotter, and winters are producing less snowfall. Table 1 summarizes recorded trends in air temperature, precipitation, ocean temperature, sea-level rise, and storminess for Rhode Island (adapted from Heffner et al. 2012).

Table 1. Climate change trends for the United States, the Northeast, and Rhode Island

Climate Change Variable	Geographic Scale	Observations of Recent Change
Air Temperature	Global	Global mean temperature has increased 1.33°F over the last 100 years
	Northeast	Since 1900, the annual mean temperature has risen 1.5°F
	Rhode Island	Average annual temperature rose 1.7°F from 1905 to 2006
Precipitation	Global	Rainfall has decreased in the Northern Hemisphere subtropics and increased in mid-latitudes over the last 50 years
	Northeast	Studies have found a 5 to 17 percent increase in regional precipitation during roughly the last 100 years
	Rhode Island	Over the past 100 years, Rhode Island precipitation has increased by 3 mm (0.12 in) per year. Annual mean wind speed at T.F. Green Airport has significantly declined since at least the 1960s
Ocean Temperature	Global	The ocean has been warming consistently over the past 50 years, with 2007 as the warmest on record
	Northeast	Annual average temperatures in the waters off the southern New England coast have increased by about 2.2°F since the 1970s

Table 1. (Continued)

Climate Change Variable	Geographic Scale	Observations of Recent Change
	Rhode Island	In Narragansett Bay, winter sea-surface temperatures have risen 4°F since the 1960s
Sea Level Rise	Global	Globally, sea-level rose in the 20th century at an average rate of 1.8 mm (0.07 in) per year, a rate greater than that of the preceding eight centuries. Between 1993 and 2003 this rate almost doubled to 3.4 mm (0.13 in) per year.
	Rhode Island	In Newport, sea-level has risen an average of 2.6 mm (0.1 in) per year since 1930
Storminess	Global	The severity of hurricanes has increased since the 1970s
	Northeast	The severity of hurricanes in the North Atlantic has increased

A comprehensive modeling effort on the projected impacts of climate change has not yet been undertaken for Rhode Island. However, Frumhoff et al. (2007b) identified the primary climate trends that could impact Rhode Island under a high emissions scenario[6] based on research conducted for the northeast region by the Union of Concerned Scientists (UCS). These primary climate trends include the following:

- Temperature: Seasonal average temperatures across Rhode Island are projected to rise 7°F to 13°F above historic levels in winter and 6°F to 14°F in summer by late-century. Figure 1 illustrates changes in the average summer heat index for Rhode Island under the high and low emission scenarios.
- Winter snow: Rhode Island could see its snow season reduced to just a few days per winter month by mid-century, and virtually eliminated by late-century.
- Drought: Rising summer temperatures, coupled with little change in summer rainfall, are projected to increase the frequency of short-term (one- to three month) droughts.
- Sea-level rise: Global sea-level is projected to rise between 10 inches and two feet by the end of the century.

These findings provide an overview of the state of knowledge regarding climate change trends and impacts as it relates to New England and Rhode Island.

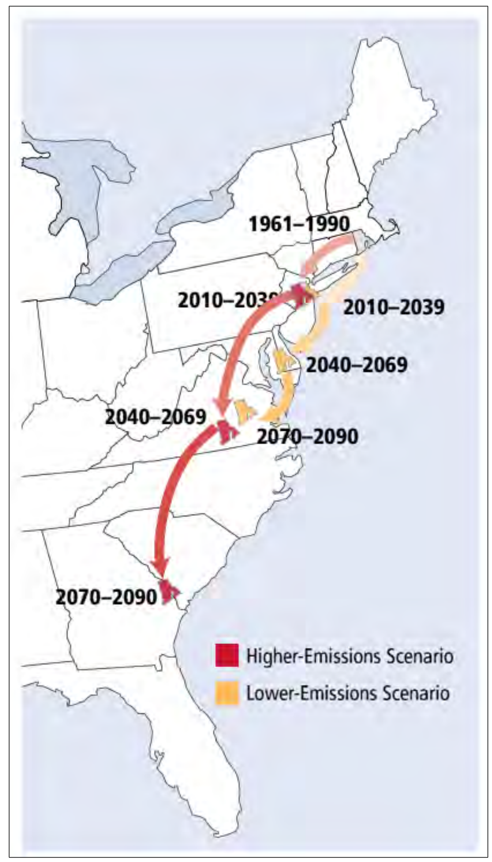


Figure 1: Migrating state climate under predicted high and low emissions scenarios

3.2 Climate Change Implications for Drinking Water Utilities

The most direct climate-change related impacts to Rhode Island water utilities are likely to be caused by changes in water availability (e.g. drought), sea-level rise, and storm intensity and frequency. Several

[6] Climate models are run against greenhouse gas emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). There are 40 different scenarios, each making different assumptions for future greenhouse gas pollution, land-use and other driving forces. The higher-emissions scenarios represent a world that experiences rapid economic growth and reliance on fossil fuels; whereas the lower-emissions represent a more ecologically friendly world.

resources describe the potential impacts of climate change on drinking water utilities in general terms, which are summarized below.

Cromwell et al. (2007) provides an overview of how drinking water utilities in various regions of the country might be impacted by climate change. Impacts on drinking water utilities relevant to Rhode Island are included in Figure 2.

Potential Climate Change Impacts on Drinking Water Utilities

Rising sea levels:

- Increased saline intrusion into groundwater aquifers
  - Water treatment challenges: increased bromide; need for desalination
- Increased salinity of brackish surface water sources
  - Water treatment challenges: increased bromide; need for desalination
- Increased risk of direct storm and flood damage to water utility facilities

Warmer overall:

- Changes in discharge characteristics of major rivers due to upstream changes
- Changes in recharge characteristics of major groundwater aquifers due to upstream changes
- Increased water temperature
  - Increased evaporation and eutrophication in surface sources
  - Water treatment and distribution challenges (disinfection, byproducts, regrowth)
- Possible increased water demand
  - Increased irrigation demand
  - Increased urban demand with more heat waves and dry spells
  - Increased drawdown of local groundwater resources to meet the above

More intense rainfall events:

- Increased turbidity and sedimentation
  - Shallower, warmer water; increased evaporation and eutrophication
  - Potential conflicts with flood control objectives
- Increased risk of direct flood damage to water utility facilities

Figure 2. Potential Climate Change Impacts on Drinking Water Utilities

Based on the findings of several climate change studies, the AWWA Research Foundation (2007) broadly categorizes potential climate change impacts on water utilities as water quality impacts, water quantity impacts, operational reliability impacts, and financial and institutional impacts. Water quality could be impacted by extreme weather (increasing sediment, pathogen loads, and urban stormwater runoff), as well as from gradual processes such as more widespread algal blooms, changes in watershed vegetation, and increased water temperature (increasing eutrophication and disinfectant demand). Water quantity will be impacted due to increasing temperature and precipitation variability—which will not be uniform across the country, and could include reduced in-stream flows, decreased snowpack, earlier and more intense snowmelt, and reduced aquifer recharge. Climate change could impact the operational reliability of drinking water utilities in a variety of ways: flood damage and pipe breaks could impact utility infrastructure, coastal facilities could be threatened by sea-level rise and increased corrosion, warmer temperatures could increase the range of invasive species such as zebra mussels; and reservoir management could be complicated by changes in runoff timing and intensity. AWWA recognized financial and institutional implications from climate change as potentially the most significant, yet least understood, issue for drinking water utilities. For example, utilities may need to design new rate structures to better reflect the increasing value of water and increasing conflict with competing water users. Climate change could also lead to population shifts that may increase or decrease a utility's customer base.

The issue of variability is stressed throughout the literature; climate change will cause increased variability for water supply planning, including changes in the capability to store water and changed water demands (Cromwell 2007; Water Utility Climate Alliance 2009; Bloetscher et al. 2010; Dorfman and Mehta 2011; Interdepartmental Climate Change Group 2009; USEPA 2009).

Strzepek et al. (2011) and USEPA (2009) describe the importance of conducting climate change assessments at the watershed level to fully identify the risks to water supply and infrastructure systems, as well as to effectively develop water resource management strategies.

The literature also states that the most useful climate change assessments are those that are tailored to the site-specific considerations and information needs of the water utility (Yates and Miller 2011; Water Utility Climate Alliance 2009; California Department of Water Resources 2008).

Recognizing the common challenges that drinking water utilities face related to climate change is useful to this project in that it assists in identifying best practices in conducting vulnerability assessments and identifying priority vulnerabilities.

3.3 Adaptation Options for Drinking Water Utilities

The most comprehensive resource for drinking water utility adaptation strategies is the *Adaptation Strategies Guide for Water Utilities* (USEPA 2012). The Guide provides adaptation options for drinking water, wastewater, and stormwater utilities based on region and projected climate impacts. Adaptation options are grouped according to impact (drought, water quality degradation, flooding, ecosystem changes, and service demand and use) and indicate relative costs are also provided for each option. Appendix E lists the adaptation options identified in the Guide for each of the climate hazards. The three categories of adaptation options included are:

- **Planning strategies:** which include use of models, research, training, supply and demand planning, natural resource management, land use planning, and collaboration at watershed and community scales;
- **Operational strategies:** which include efficiency improvements, monitoring, inspections, conservation, demand management, flexible operations, and sustainable strategies; and
- **Capital / infrastructure strategies:** which include construction, water resource diversification, repairs and retrofits, upgrades, phased construction, new technology adoption, and green infrastructure.

The literature review also identified several beneficial case studies, as these evaluate adaptation options that have been or are being applied in a specific context (Ewert 2011; Interdepartmental Climate Change Group 2009; Ofwat 2008; USEPA 2011; WSAA 2011; Yates and Miller 2011). The case study of New York City is considered particularly relevant, as the city is one of the few in the country that has conducted a climate vulnerability assessment and adaptation planning inclusive of drinking water utilities. The City is also located in the Northeast, in close proximity to the Atlantic Ocean, and will experience similar climate hazards to Rhode Island.

As identified in Dorfman and Mehta (2011), the New York City Department of Environmental Protection (NYC DEP), the agency responsible for managing the city's water supply, sewer, and wastewater treatment; implemented the following ongoing adaptation efforts, primarily due to concern for the city's aging infrastructure and vulnerability to sea-level rise, drought, and increased flood events:

- increased water conservation through rebate programs;
- implementation of low-impact development strategies;
- maximization of water supplies from existing facilities;
- conversion of combined sewers into high-level storm sewers (HLSS) that capture and transport rainfall directly to waterways, thereby reducing the volume of stormwater flowing into the sewer system; and
- infrastructure improvements to enhance reliability of water distribution systems.

NYC DEP is also working on actions that will address climate change over the long term, such as:

- development of a methodology for including climate change impacts in the City Environmental Quality Review process;
- consideration of future sea and tide levels in sewer design and siting of outfalls;
- inclusion of climate change as a risk when prioritizing projects; and
- identification of vulnerable infrastructure and inclusion of flood protection measures in capital improvement funding cycles.

Loftus (2011b) notes that New York City is following an integrated planning approach, whereby adaptation planning is driven by a multi-stakeholder involvement process which has placed special importance on the role of scientific research, particularly in the steps linked to forecasting climate change impacts and assessing vulnerability. Rosenzweig (2007) further describes the adaptation framework being used by NYC DEP, which details the 9-step adaptation assessment procedure, consisting of the following steps:

- Conduct adaptation assessment
- Identify risk
- Identify main climate change impacts to that project
- Apply future climate change scenarios
- Characterize adaptation options
- Conduct initial feasibility screening
- Link to capital cycles
- Evaluate options: e.g., benefit and cost analysis
- Develop implementation plans, including timeframe for implementation
- Monitor and reassess

Within the assessment procedure, climate change adaptations are divided into management, infrastructure, and policy categories, and are assessed by their relevance in terms of climate change time-frame (immediate, medium, and long term), the capital cycle, costs, and other impacts.

A case study by Bloetscher et al. (2010) of the City of Pompano Beach Water Utility provides a useful summary of adaptation options associated with water conservation programs. The case study notes that to be effective, water conservation programs should be an ongoing effort since it can take years to achieve significant results, and that they are most appropriate where there is no driver for immediate reduced demand. The study also presents issues associated with utility economics and capacity under-utilization, where reduced demand decreases revenues that cannot be offset without cost increases. Thus, effective conservation programs may require the utility to increase rates or impose surcharges on the public to meet bond covenants and legal requirements. Capacity underutilization can also cause operating problems requiring increased maintenance (i.e., line flushing). The study notes that these problems are generally offset in those cases where population growth increases demand, capacity utilization, and revenues.

Non-emergency water conservation program tools that are commonly employed by utilities include:

- Meter reading/water billing
- Inverted block water rates (pay more for higher use)
- Leak detection and repair of faucets, toilets, pipes, etc.
- Pressure reduction to the distribution system to reduce water use
- Regional-imposed irrigation restrictions and daytime watering bans (to reduce evaporation loss)
- Educational outreach programs, billing inserts, etc. with tips for how to conserve water
- Seasonal water rates
- Distribution system leak detection programs

Programs that require the support of local government include:

- Building Code changes that require high efficiency water fixtures and rain sensors with automatic shut-off in new construction and major renovations
- High-efficiency clothes washer rebates
- Grants for water conservation (i.e., grants for migrating away from potable water use and changing plumbing fixtures)
- Ultra low flush (ULF) toilet rebates

The adaptation options identified in the literature review will be evaluated for applicability to Rhode Island drinking water utilities in Phase 3: Development of Management Strategies.

4.0 DATA COLLECTION FOR MODELING EFFORTS

Tetra Tech collected data sets under Phase 1 which will be used for modeling efforts in the next phase of the project. Table 2 summarizes the type of data, source, and anticipated use for climate vulnerability modeling and assessment.

Table 2. Data sets collected under Phase 1 for Phase 2 modeling efforts

Data Type	Source	Model
Digital Elevation Model (3m resolution)	U.S. Geological Survey (USGS)	SWAT (setup)
Land Use Land Cover (NLCD 2006)	Multi-Resolution Land Characteristics Consortium	SWAT (setup)
Soils (SSURGO)	Natural Resource Conservation Service	SWAT (setup)
Point Sources	Department of Environmental Management (Deb Merill)	SWAT (setup)
Weather (Daily precipitation and temperature)	EPA BASINS	SWAT (setup)
Scituate reservoir operation data	Providence Water	SWAT (setup)
Flat River reservoir operation (limited information)	Quidnick Reservoir Company	SWAT (setup)
Daily flow	USGS National Water Information System	SWAT (calibration)
Erosion Rates	Coastal Resources Management Council	HAZUS (Coastal Flood, SLR, and Surge)

Table 2. (Continued)

Data Type	Source	Phase 2 Model
Digital Elevation Model (3m resolution)	USGS	HAZUS (Flood, SLR, Surge)
Flood Maps and Flood Insurance Studies	Federal Emergency Management Agency	Stillwater Elevations and HAZUS Calibration/Validation
Infrastructure Data	Water Utilities	HAZUS
Infrastructure Data	Water Resources Board	HAZUS
Tide Measurements	National Oceanic and Atmospheric Administration	Sea-Level Rise Analysis

5.0 NEXT STEPS

The *Safe***Water** RI project is iterative, with each phase building on the previous phase(s). The primary data collection efforts have established a baseline of understanding of the viewpoints and activities of water utility partners which will be used to inform the remaining *Safe***Water** RI project phases. For example, the identification of priority issues and key challenges of the water utilities will assist in developing appropriate adaptation options (Phase 3: Development of Management Strategies), while understanding the utility stakeholder perceptions of climate change and extreme weather will assist in the development of education and outreach strategies (Phase 4: Outreach and Education). Developing and maintaining relationships with the water utility partners will also assist in facilitating the ultimate “buy-in” of the project recommendations.

The results of the desktop literature review provide data on the state of knowledge of climate trends and impacts of the Northeast and Rhode Island. Phase 2 of the *Safe***Water** RI project (Assessment of Impacts) will use the data collected in Phase 1 and identified in Section 4 above. The literature review also identified the most relevant and comprehensive sources of information related to adaptation options for drinking water utilities. Adaptation options will be assessed in Phase 3 of this project (Development of Management Strategies).

A. Survey Questions

Ensuring Safe Water for Rhode Island’s Future

Welcome

Thank you for taking the time to participate in the Rhode Island Department of Health (HEALTH), Office of Drinking Water Quality’s project Ensuring Safe Water for Rhode Island’s Future. The objective of this project is to assess Rhode Island’s changing environmental conditions (including temperature, precipitation patterns, sea level rise, and storm surge) and the potential impacts faced by drinking water utilities to develop effective management strategies. This project is in response to several extreme weather events that have occurred in Rhode Island, such as the 1999 drought and the 2010 flood. This project will evaluate current water quality, water availability, and infrastructure conditions; assess how those conditions could change in the future; and recommend adaptation strategies.

1. What is your first and last name? Please note: All personal details are kept private and confidential. Survey participants will remain anonymous in all presentations of the survey results.

2. What is your current position?

3. What is the name of the water utility where you are employed?

4. What is the length of time that you have been employed at the water utility?

- ◯ 0-1 year
- ◯ 2-5 years
- ◯ 6-10 years
- ◯ 11-15 years
- ◯ 16-20 years
- ◯ Over 20 years

5. Please indicate how many years of experience you have in the industry.

- ◯ 0-1 year
- ◯ 2-5 years
- ◯ 6-10 years
- ◯ 11-15 years
- ◯ 16-20 years
- ◯ Over 20 years

The next two questions refer to concerns that you may face under two different planning horizons (0 to 5-year planning horizon and 5 to 30-year planning horizon).

6. Please rank the following concerns as they relate to the viability of your water utility for the <u>0 to 5-year planning horizon</u>. Please rank each item as very important, important, not important, or don't know.

	Very Important	Important	Not Important	Don’t Know
Drought (i.e., safe water yields)	◯	◯	◯	◯
Population growth	◯	◯	◯	◯
Aging infrastructure	◯	◯	◯	◯
Extreme weather events (i.e., flood, storm surge, wind damage)	◯	◯	◯	◯
Sea level rise	◯	◯	◯	◯
Groundwater aquifer depletion	◯	◯	◯	◯
Competing water demands (i.e., purchased water, agriculture versus urban demands)	◯	◯	◯	◯
Storage capacity	◯	◯	◯	◯
Water quality (i.e., contaminants, nutrients, sedimentation)	◯	◯	◯	◯
Regulatory restrictions/mandates	◯	◯	◯	◯
Public health	◯	◯	◯	◯
Financial	◯	◯	◯	◯

Other concern(s) not identified above.

7. Please rank these same concerns from Question 6 as they relate to your water utility's viability in the 5 to 30-year planning horizon. Please rank each item as very important, important, not important, or don't know.

	Very Important	Important	Not Important	Don't Know
Drought	○	○	○	○
Population growth	○	○	○	○
Aging infrastructure	○	○	○	○
Extreme weather event (i.e., flood, storm surge, wind damage)	○	○	○	○
Sea level rise	○	○	○	○
Groundwater aquifer depletion	○	○	○	○
Competing water demands (i.e., purchased water, agriculture versus urban demands)	○	○	○	○
Storage capacity	○	○	○	○
Water quality (i.e., contaminants, sedimentation)	○	○	○	○
Regulatory restrictions/mandates	○	○	○	○
Financial	○	○	○	○
Public health	○	○	○	○

Other concern(s) not identified above.

8. What strategies and techniques (e.g., capital improvement plans, water conservation programs, technological improvements) do you use to manage the current water quality, water availability, and infrastructure needs that your utility faces? Please describe briefly below.

9. What obstacles (if any) have hindered or prevented implementation of the strategy(ies) identified in Question 8. Please check all that apply.

- [ ] Economic
- [ ] Social
- [ ] Technical
- [ ] Administrative
- [ ] Political
- [ ] Legal
- [ ] Environmental

Other obstacle(s) not identified above.

10. Please indicate the current planning horizons that your utility uses for capital planning and water management strategies. Check all that are appropriate.

- [ ] 0-1 year
- [ ] 2-3 years
- [ ] 4-5 years
- [ ] 6-10 years
- [ ] 11-15 years
- [ ] 16-20 years
- [ ] Greater than 20 years

Other planning horizons (please specify).

11. Does your utility use specific decision support tools or techniques (e.g, modeling software tools such as EPANET and InfoWorks; techniques such as the IWA/AWWA Water Audit Method; or datasets from the USGS National Water-Quality Assessment Program) for assessing future risk and demand? If yes, please list below.

12. Are you concerned about the potential impacts of climate change on your water utility?

- ◯ Yes, Very Concerned
- ◯ Somewhat Concerned
- ◯ Not Concerned
- ◯ Don't Know

13. Would you consider your stakeholders (e.g., elected officials, water board members, customers) more open to proactive or reactive measures when it comes to addressing the impacts of weather-related events?

	Proactive	Reactive	Don't Know
Elected Officials	◯	◯	◯
Water Board Members	◯	◯	◯
Customers	◯	◯	◯

Thank You!

Thank you for taking the time to participate in this survey. The results of the survey will be collected and presented at an upcoming water utility partner meeting, tentatively scheduled for February 29 at 1:30 PM in Providence. An invitation to the meeting will be sent to each of the utilities shortly. We look forward to working with you throughout this project.

B. Phase 1 Participation Summary

Appendix B
Phase I Participation Summary

Organization	Name	Title	Phase 1 Participation	
			Survey	Kick-off Meeting
Block Island Water Company	Simmons, David	Superintendent	X	
Bristol County Water Authority	Marchand, Pamela	Executive Director	X	X
City of East Providence	Marvel, Jim	Interim Superintendent	X	
City of Newport	Forgue, Julia	Director of Utilities	X	
City of Woonsocket	McGauvran, Sheila	Director of Public Works	X	
East Smithfield Water District	DiSanto, Raymond (Ray)	General Manager	X	X
Harrisville Fire District Water Dept	Bisson, Paul	Superintendent	X	X
Jamestown Water Department	Gray, Michael	Public Works Director	X	X
Johnston Water Control Facility – West End	Caruso, Lori	Johnston Town Engineer	X	X
Kingston Water District	Meyer, Henry	Manager	X	
Lincoln Water Commission	Faile, John	Superintendent	X	
Naval Station Newport	Abraham, Scott	Utilities Work Leader	X	X
Naval Station Newport	Ward, Darlene	Environmental Work Leader		X
North Tiverton Fire District	Perry, Jason	Superintendent	X	
Pascoag Utility District	Kirkwood, Michael	General Manager	X	
Pawtucket Water Supply Board	DeCelles, James	Chief Engineer & General Manager	X	
Portsmouth Water & Fire District	Driscoll, Phil	Water Board Member		X
Portsmouth Water & Fire District	Lister, Nathan	Operator		X
Portsmouth Water & Fire District	McGlinn, William (Bill)	General Manager and Chief Engineer	X	
Providence Water Supply Board	Thompson, Jeff	Technical Advisor to General Manager	X	
RI Department of Environmental Management, Office of Water Resources	Patenaude, Bill	Principal Engineer		X
RI Department of Health, Office of Water	Swallow, June	Chief		X
RI Department of Health, Office of Water	Boudreau, Steven	Program Manager		X
Stone Bridge Fire District	Destremps, Carl	Superintendent	X	
Town of Cumberland	Champi, Chris	Superintendent	X	
Town of North Kingstown	Licardi, Susan	n/a		X
Town of South Kingstown	Schock, Jon	Public Services Director	X	
U of Rhode Island	Bozikowski, Robert (Bob)	Water System Manager	X	X
Westerly Water Dept.	Corina, Paul	Superintendent	X	

C. *Safe*Water RI Kick-off Meeting and Survey Results

SafeWater RI

ENSURING SAFE WATER FOR RHODE ISLAND'S FUTURE

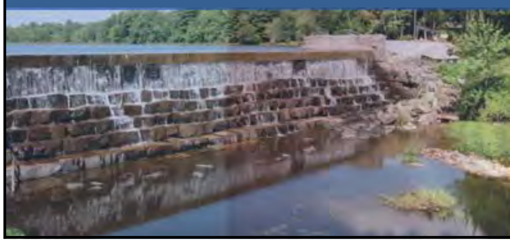
RHODE ISLAND DEPARTMENT OF HEALTH

TETRA TECH

Ensuring Safe Water for Rhode Island's Future

Kickoff Meeting

February 29, 2012




Agenda

- Introductions and overview of *Safe*Water RI project
- Presentation of survey results
- Facilitated discussion with utility representatives
- Identification of additional data needs
- Action items and next steps

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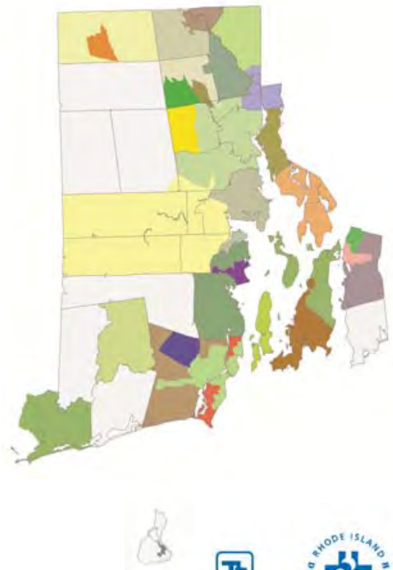
*Safe*Water RI



Objectives

- Assess changing environmental conditions and potential impacts on RI drinking water utilities
- Develop strategies to address these changing conditions

Guiding Principles

- Broad engagement with RI drinking water utilities
- Innovative modeling to provide accurate and scalable results

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*Safe*Water RI

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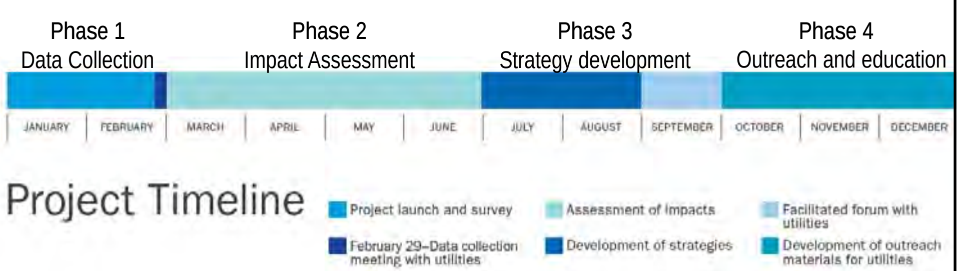
Phases of Project



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*Safe*Water RI

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Phase 1: Data Collection

- Survey to utilities
- Datasets for impact assessment (meteorological, water quality, infrastructure assets,
- Review of policies and regulations

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Phase 2: Assessment of Impacts

- Identify which assets need to be protected and from what hazards
- Help justify any action which requires funding and
- Help determine the physical characteristics of some management strategies.

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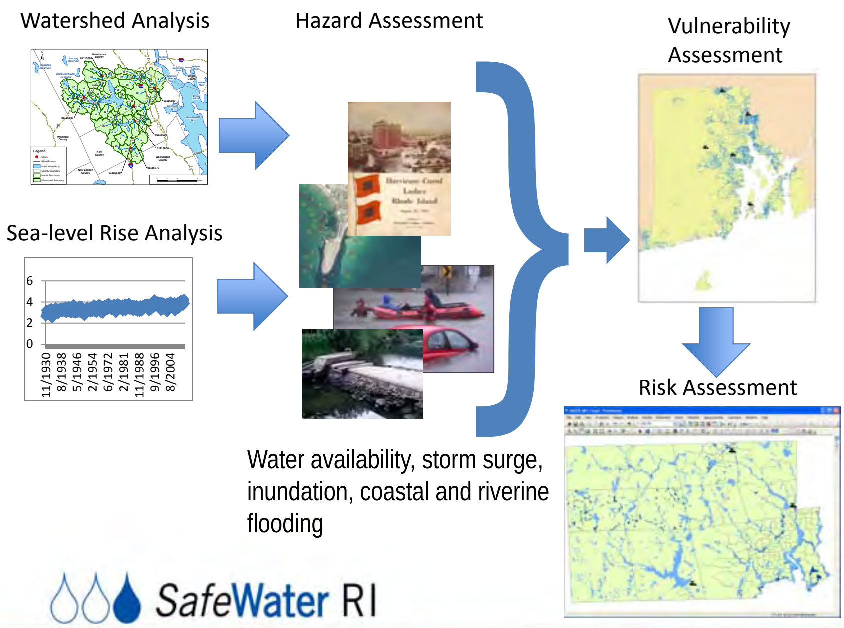

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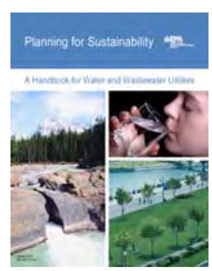
Phase 3: Development of Management Strategies

- Evaluate management options using STAPLEE (Social, Technical, Administrative, Political, Legal, Environmental, and Economic) criteria
- Conduct cost-benefit analysis of options
- Identify short-term and long-term management strategies



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Phase 4: Outreach and Education

- Follow-up forum with utilities on recommended strategies
- Development of outreach and education strategy for utilities to work with customers
- Preparation of outreach materials

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Survey Results

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Q3. What is the name of the water utility where you are employed?

- Block Island Water Company
- Bristol County Water Authority
- City of East Providence
- City of Newport
- City of Woonsocket
- East Smithfield Water District
- Harrisville Fire District Water Dept
- Jamestown Water Department
- Johnston Water Control Facility – West End
- Kingston Water District
- Lincoln Water Commission
- Naval Station Newport
- North Tiverton Fire District
- Pascoag Utility District
- Pawtucket Water Supply Board
- Portsmouth Water & Fire District
- Providence Water Supply Board
- Stone Bridge Fire District
- Town of Cumberland
- Town of South Kingstown
- U of Rhode Island
- Westerly Water Dept.

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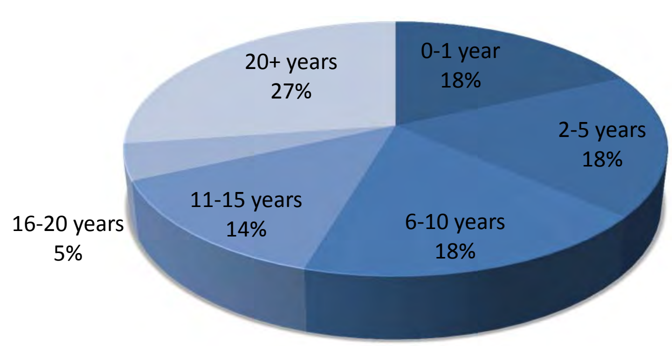
Q4: What is the length of time you have been employed at the water utility?



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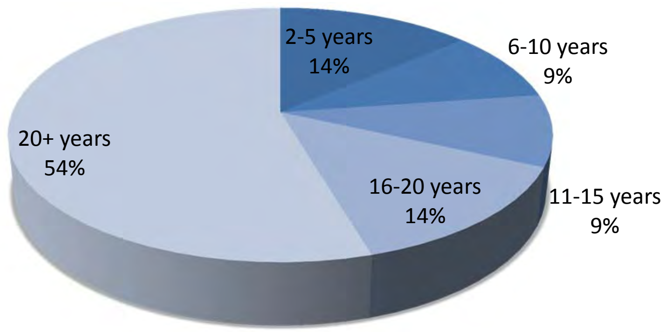
Q5. Please indicate how many years of experience you have in the industry.



Note: "0-1 Years" = 0%

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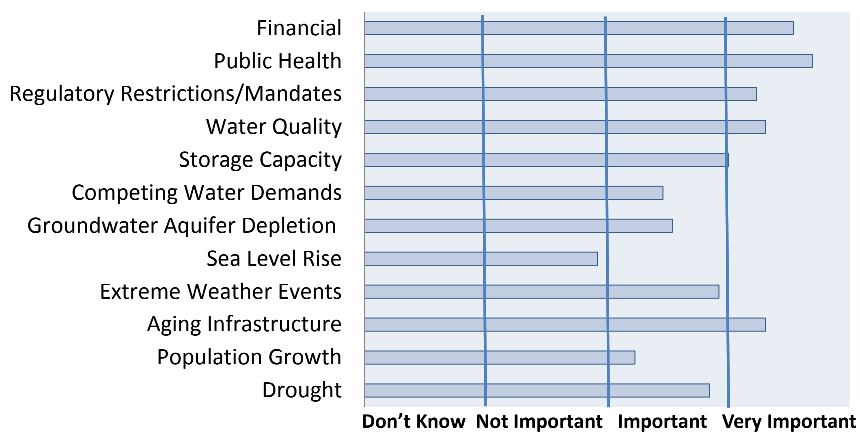
Q6. Rank the following concerns as they relate to the viability of your water utility for the 0 to 5-year planning horizon.



Note: Results are based on the weighted average of responses

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Top five concerns about the viability of the water utility for the next five years:

1. Public Health
2. Financial
3. Water Quality
4. Aging Infrastructure
5. Regulatory Restrictions

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Q6. Rank the following concerns as they relate to the viability of your water utility for the 0 to 5-year planning horizon.

- Additional responses:
  - Diminishing ability to find new water sources
  - Emergency Interconnections
  - Lack of qualified operators
  - Too many "small" water districts with insufficient backup and redundancy
  - Water quality issues from deteriorating infrastructure

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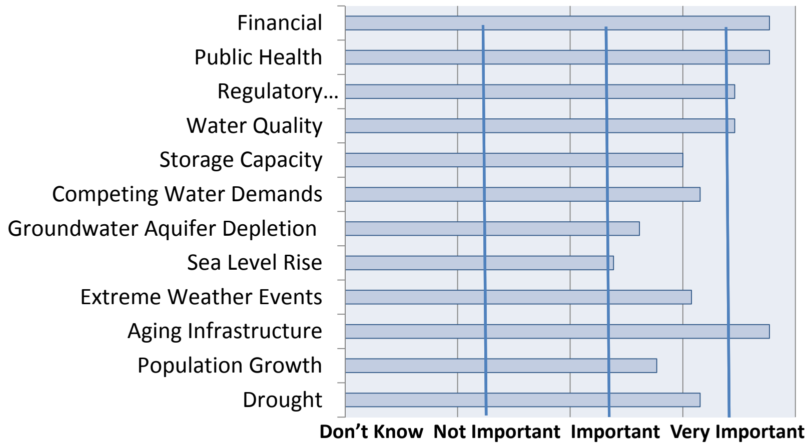
Q7. Please rank these same concerns from Question 6 as they relate to your water utility's viability in the 5 to 30-year planning horizon.



Note: Results are based on the weighted average of responses

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Top five concerns about the viability of the water utility for the 5 to 30 year time frame:

1. Aging Infrastructure
2. Public Health
3. Financial
4. Water Quality
5. Regulatory Restrictions

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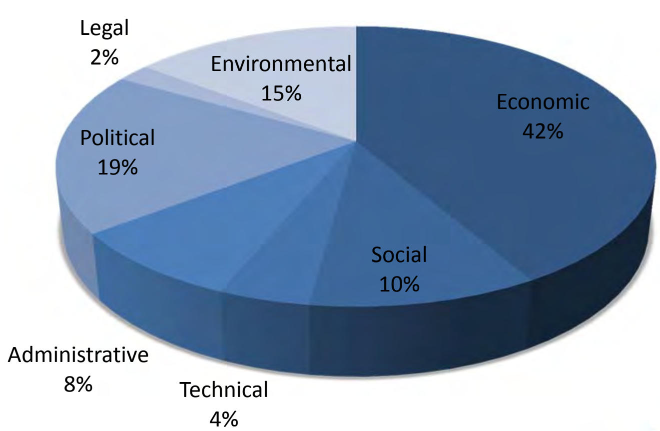
Q8: What strategies and techniques do you use to manage the current water quality, water availability, and infrastructure needs that your utility faces?

- Aggressive water quality monitoring, communication, demand management and maintenance
  - Leak detection
  - Block rate pricing
  - Outside water use restrictions
  - Unidirectional flushing program
  - Leak detection and notification programs
- Assessment and Planning Reports:
  - Source protection plans
  - GIS
  - USGA groundwater reports and models
  - Hydraulic models
  - Rate Studies
- Maintenance, repair & replacement of aging infrastructure
  - Focus on financial planning, capital improvements
  - Aggressively identify potential problem areas
  - Meter upgrades
  - Replacement/upgrades of storage tanks, water mains, wells and facilities
  - Cleaning and lining of pipes
- Gradual rate increases tend to result in conservation measures and generally yield no increase in revenue

Q9: What obstacles (if any) have hindered or prevented implementation of the strategies identified in Question 8.



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Q9: What obstacles (if any) have hindered or prevented implementation of the strategies identified in Question 8.

Additional responses:

- Not having a system owned water supply
- Regulatory
- Lack of qualified water system operators
- Watershed limitations for supply

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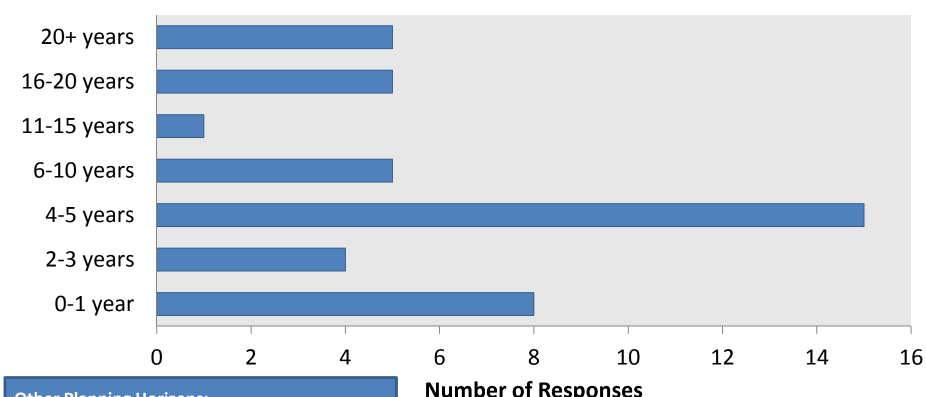
Q10: Please indicate the current planning horizons that your utility uses for capital planning & water management strategies.



Other Planning Horizons:
- Will be initiating 5, 10, 20 year planning
- Working on longer term, 20 year plan

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Q11: Does your utility use specific decision support tools or techniques (e.g, modeling software tools such as EPANET and InfoWorks; techniques such as the IWA/AWWA Water Audit Method; or datasets from the USGS National Water-Quality Assessment Program) for assessing future risk and demand?

- EPANET
- Modified AWWA Water Audit Method
- For demand: US Census, State Population projections, historical connection rate and water demand trends
- Vulnerability assessments, emergency response planning

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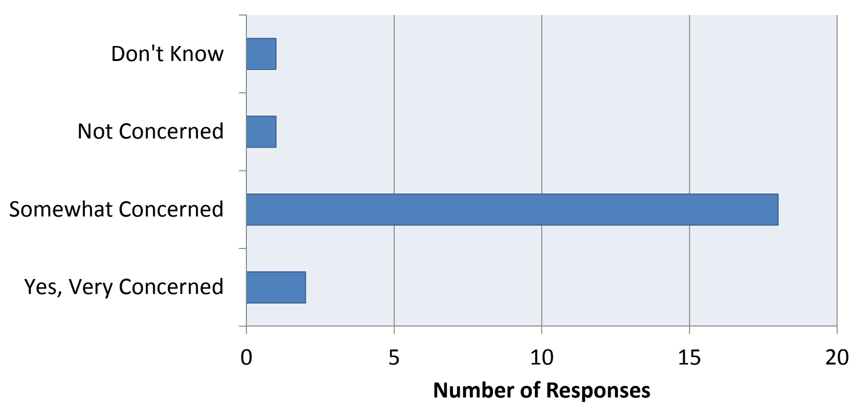
Q12: Are you concerned about the potential impacts of climate change on your water utility?



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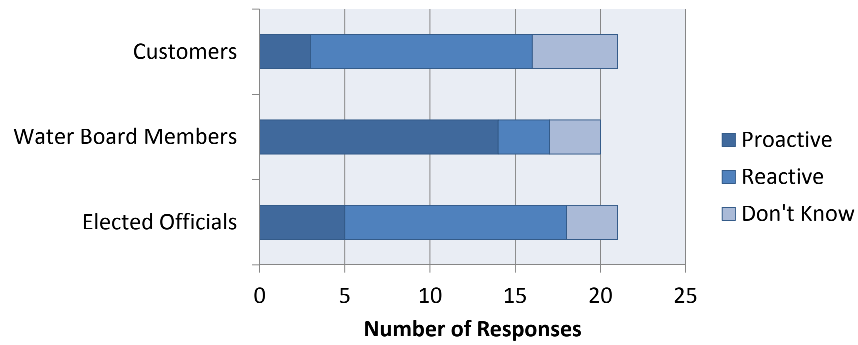
ENSURING SAFE WATER FOR RHODE ISLAND'S FUTURE

Q13. Would you consider your stakeholders more open to proactive or reactive measures when it comes to addressing the impacts of weather-related events?



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Ensuring Safe Water for Rhode Island's Future

Kickoff Meeting

February 29, 2012

D. Literature Review Resources

Appendix D
Literature Review Resources

The following resources were compiled through desktop research and consultations as part of the *Safe***Water** RI project. The list is not intended to be exhaustive or complete, but the resources included are considered the most relevant/illustrative secondary information sources to research the following issues: 1) the state of knowledge regarding climate change trends for the Northeast and specifically Rhode Island; 2) potential climate change impacts on drinking water utilities; and 3) best practices used in adaptation strategies for drinking water utilities.

The literature review resources are organized into five sections:

1. **Climate Trends.** Resources that include pertinent information on observed and/or projected climate trends.
2. **Rhode Island Government Resources**. Relevant government resources and authorities for the *Safe***Water** RI project. These resources will be used to ensure regulatory compliance with proposed adaptation options and identify planning synergies associated with the *Safe***Water** RI project.[1]
3. **Rhode Island: Additional Climate Resources**. A listing of climate resources that have been developed by coalitions and associations for the state.
4. **Understanding and Managing Climate Risk.** Representative information on how municipalities and communities have approached climate risk management, including the role of state and local government action.
5. **Water Utilities: Climate Change Vulnerability Assessment and Adaptation Planning.** A listing of resources that specifically address climate vulnerability assessment and best practices in adaptation for drinking water utilities.

All publications referenced in this literature review can be accessed and downloaded through the *Safe***Water** RI ftp site (access information included below). Publications on the ftp site have been saved in the format “Author(s), Year” and in the respective section folder.

*Safe***Water** *RI FTP Site*: ftp://rhode_island/array1/RICC/

Note: Please copy and paste the link into Windows explorer to access it.

[1] Note that resources that directly or indirectly inform climate change with respect to water resources are included and is in no way exhaustive of all relevant Rhode Island Government resources.

1. Climate Trends

Ashton, A., J. Donnelly, and R. Evans. 2007. *A Discussion of the Potential Impacts of Climate Change on the Shorelines of the Northeastern USA.* Northeast Climate Impacts Assessment, Union of Concerned Scientists, Available online at: http://www.whoi.edu/science/GG/coastal/publications/pdfs/AshtonDonnellyEvans_MITI2007.pdf.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds. 2008. *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

Christensen, J. H., B. Hewitson, et al. 2007. Regional Climate Projections. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. New York, NY, Cambridge University Press.

Covich, A. 2009. *Emerging Climate Change Impacts on Freshwater Resources: A Perspective on Transformed Watersheds*. Report, Resources for the Future, Washington, D.C.

Frumhoff, P. C., J. J. McCarthy, et al. 2007a. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA, Union of Concerned Scientists (UCS).

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007b. *Rhode Island Report*, in Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Cambridge, MA, Union of Concerned Scientists (UCS).

Hapke, C.J., Himmelstoss, E.A., Kratzmann, M., List, J.H., and Thieler, E.R. 2010. *National assessment of shoreline change; historical shoreline change along the New England and Mid-Atlantic coasts.* U.S. Geological Survey Open-File Report 2010-1118. Available online at: http://pubs.usgs.gov/of/2010/1118/.

Heffner, L., R. Williams, V. Lee, P. Rubinoff, C. Lord. 2012. *Climate Change and Rhode Island's Coasts: Past, Present, and Future*. URI Coastal Resources Center and Rhode Island Sea Grant, Providence, Rhode Island.

Hodgkins, G. A., and R. W. Dudley. 2011. Historical summer base flow and stormflow trends for New England Rivers, *Water Resources Research*, 47.

Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian. 2007. Coastal Flooding in the Northeastern United States due to Climate Change. In press for the journal *Mitigation and Adaptation Strategies for Global Change*, as part of the special issue: "Northeast United States Climate Impact Assessment".

Mendelsohn, R., K. Emanuel, and S. Chonabayashi. 2011. *The Impact of Climate Change on Hurricane Damages in the United States*. Available online: http://www.gfdrr.org/gfdrr/sites/gfdrr.org/files/New%20Folder/The%20Impact%20of%20Climate%20Change%20on%20Global%20Tropical%20Storm%20Damages.pdf.

Roy, S., L. Chen, E. Girvetz, E. Maurer, W. Mills, and T. Grieb. 2010. *Evaluating Sustainability of Projected Water Demands Under Future Climate Change Scenarios*. National Resources Defense Council, New York, New York.

Union of Concerned Scientists (UCS). 2006. *Climate Change in the U.S. Northeast - A Report of the Northeast Climate Impacts Assessment*. Available online at: http://www.ucsusa.org/assets/documents/global_warming/necia_climate_report_final.pdf.

2. Rhode Island Government Resources

Rhode Island Division of Planning. 2012. *Rhode Island Water 2030*. State Guide Plan Element 721, Report, Available online: http://www.planning.ri.gov/.

Rhode Island Emergency Management Agency. 2012. *Rhode Island State Hazard Mitigation Plan*. April 2011, Providence, Rhode Island.

Rhode Island General Assembly. 2011. An Act Relating to Health and Safety – Energy Independence, Introduced March 23, 2011, Senate 0724.

Rhode Island General Assembly. 2010. An Act Relating to Health and Safety – Climate Risk Reduction Act, Introduced February 11, 2010, Senate 2439.

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E. Adaptation Options for Drinking Water Utilities

Appendix E
Adaptation Options for Drinking Water Utilities

The U.S. Environmental Protection Agency's *Adaptation Strategies Guide for Water Utilities* was identified in the literature review as the most comprehensive resource for drinking water utility adaptation strategies (2012). The Guide provides adaptation options for drinking water, wastewater, and stormwater utilities based on region and projected climate impacts. The three categories of adaptation options included are:

- **Planning strategies:** which include use of models, research, training, supply and demand planning, natural resource management, land use planning, and collaboration at watershed and community scales;
- **Operational strategies:** which include efficiency improvements, monitoring, inspections, conservation, demand management, flexible operations, and sustainable strategies; and
- **Capital / infrastructure strategies:** which include construction, water resource diversification, repairs and retrofits, upgrades, phased construction, new technology adoption, and green infrastructure.

Adaptation options are grouped according to impact (drought, water quality degradation, flooding, ecosystem changes, and service demand and use) and indicate relative costs are also provided for each option. The table below lists the key adaptation options identified in the Guide for each of the climate hazards.

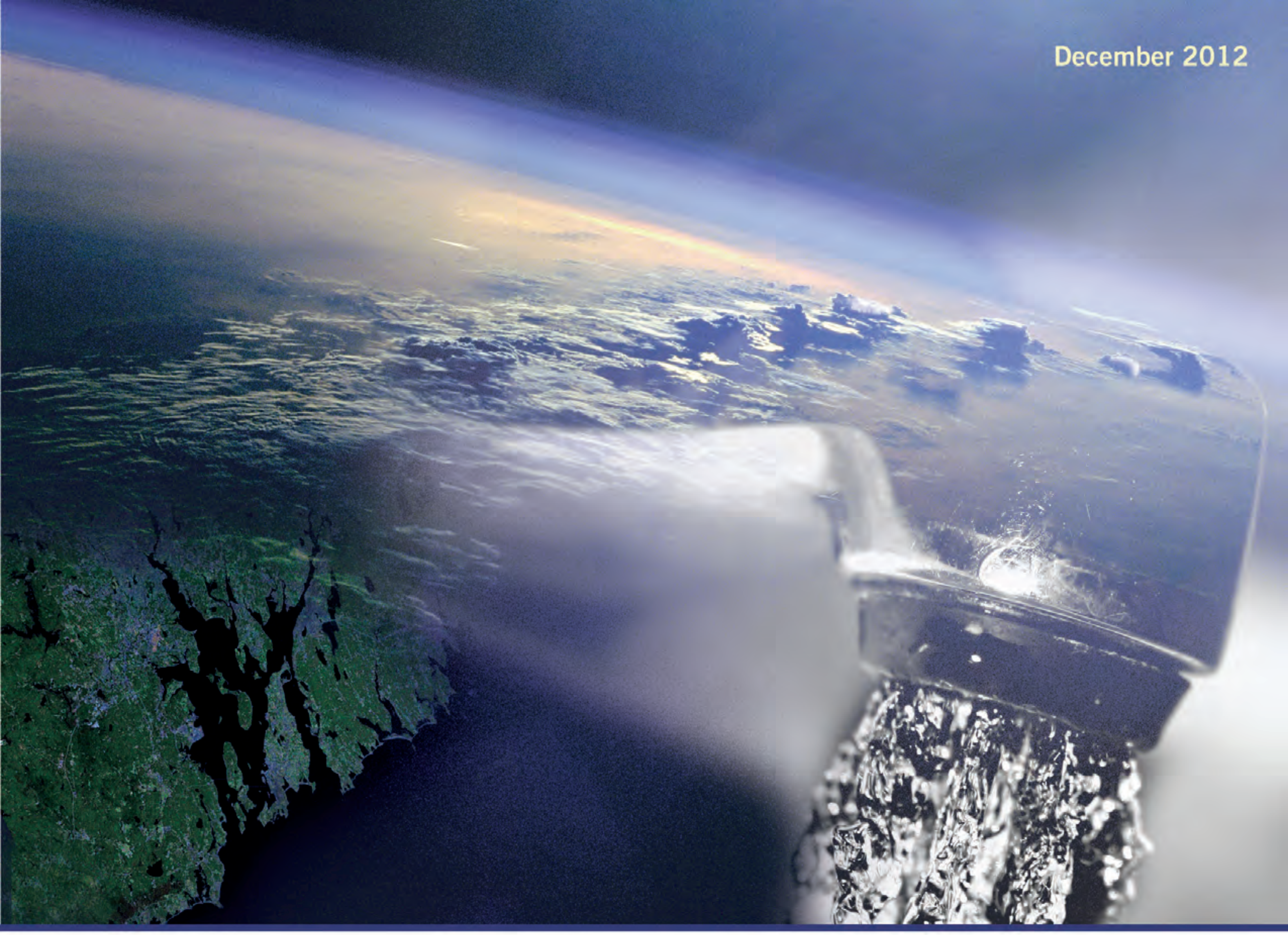
Drought	
Planning Strategies	
Develop models to understand potential water quality changes (e.g., increased turbidity) and costs of resultant changes in treatment.	$
Use hydrologic models to project runoff and incorporate model results during water supply planning.	$
Conduct training for personnel in climate change impacts and adaptation strategies.	$
Participate in community planning and regional collaborations related to climate change adaptation.	$-$$
Operational Strategies	
Finance and facilitate systems to recycle water, including use of greywater in homes and businesses.	$$-$$$
Practice conjunctive use (i.e., optimal use of surface water and groundwater).	$$-$$$
Reduce agricultural and irrigation water demand by working with irrigators to install advanced equipment (e.g., drip or other micro-irrigation systems with weather-linked controls).	$$-$$$
Practice demand management through communication to public on water conservation actions.	$
Practice water conservation and demand management through water metering, rebates for water conserving appliances/toilets and/or rainwater harvesting tanks.	$-$$
Capital / Infrastructure Strategies	
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs and/or dams.	$$-$$$
Acquire and manage ecosystems, such as forested watersheds, vegetation strips, and wetlands, to regulate runoff.	$$$
Build infrastructure needed for aquifer storage and recovery, (either for seasonal storage or longer-term water banking), (e.g., recharge canals, recovery wells).	$$$
Diversify options to complement current water supply, including recycled water, desalination, conjunctive use, and stormwater capture.	$$$
Retrofit intakes to accommodate decreased flow in source waters.	$$-$$$
Build or expand infrastructure to support conjunctive use.	$$$

Water Quality Degradation	
Planning Strategies	
Develop models to understand potential changes (e.g., increased turbidity, sea level rise, saltwater intrusion) and costs of impacts.	$
Conduct training for personnel in climate change impacts and adaptation strategies.	$
Participate in community planning and regional collaborations related to climate change adaptation.	$-$$
Develop emergency response plans to deal with the relevant natural disasters and include stakeholder engagement and communication.	$
Operational Strategies	
Practice fire management plans in the watershed, such as mechanical thinning, weed control, selective harvesting, controlled burns and creation of fire breaks.	$-$$
Monitor vegetation changes in watersheds.	$
Monitor flood events and drivers that may impact flood and water quality models (e.g., precipitation, catchment runoff).	$
Manage reservoir water quality by investing in practices such as lake aeration to minimize algal blooms due to higher temperatures.	$$
Monitor current weather conditions, including precipitation and temperature.	$
Finance and facilitate systems to recycle water to decrease discharges to receiving waters.	$$-$$$
Monitor surface water conditions, including water quality in receiving bodies.	$
Finance and facilitate systems to recycle water, including use of greywater in homes and businesses.	$$-$$$
Reduce agricultural and irrigation water demand by working with irrigators to install advanced equipment (e.g., drip or other micro-irrigation systems with weather-linked controls).	$$-$$$
Practice water conservation and demand management through water metering, rebates for water conserving appliances/toilets and/or rainwater harvesting tanks.	$-$$
Capital / Infrastructure Strategies	
Diversify options to complement current water supply, including recycled water, desalination, conjunctive use, and stormwater capture.	$$$
Increase treatment capabilities and capacities to address decreased water quality due to saltwater	$$$
Implement barriers and aquifer recharge to limit effects of saltwater intrusion. Consider use of reclaimed water to create saltwater intrusion barriers.	$$$
Install low-head dams to separate saltwater wedge from intakes upstream in the freshwater pool.	$$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs and/or dams.	$$-$$$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Implement watershed management practices to limit pollutant runoff to reservoirs.$$	
Increase treatment capabilities to address water quality changes (e.g., increased turbidity).	$$$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Implement or retrofit source control measures that address altered influent flow and quality at treatment plants.	$$-$$$

Flooding	
Planning Strategies	
Integrate flood management and modeling into land use planning.	$
Implement policies and procedures for post-flood repairs.	$
Participate in community planning and regional collaborations related to climate change adaptation.	$-$$
Integrate climate-related risks into capital improvement plans, including flood-proofing options to build facility resilience against current and potential future risks.	$
Identify and protect vulnerable facilities, including developing operational strategies that isolate these facilities and re-route flows.	$-$$
Establish mutual aid agreements with neighboring utilities.	$
Ensure that emergency response plans deal with flooding contingencies and include stakeholder engagement and communication.	$
Conduct training for personnel in climate change impacts and adaptation.	$
Adopt insurance mechanisms and other financial instruments, such as catastrophe bonds, to protect against financial losses associated with infrastructure losses.	$
Plan for alternative power supplies to support operations in case of loss of power.	$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Develop models to understand potential water quality changes (e.g., increased turbidity) and costs of resultant changes in treatment.	$
Operational Strategies	
Monitor and inspect the integrity of existing infrastructure.	$-$$
Monitor surface water conditions, including streamflow and water quality.	$
Monitor flood events and drivers that may impact flood and water quality models (e.g., precipitation, catchment runoff).	$
Capital / Infrastructure Strategies	
Acquire and manage coastal ecosystems, such as coastal wetlands, to attenuate storm surge and reduce coastal flooding ("soft protection").	$$$
Increase treatment capabilities to address water quality changes (e.g., increased turbidity)	$$$
Relocate facilities (e.g., treatment plants) to higher ground.	$$$
Establish alternative power supplies, potentially through on-site generation, to support operations in case of loss of power.	$-$$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Diversify options to complement current water supply, including recycled water, desalination, conjunctive use, and stormwater capture.	$$$
Build flood barriers, sea walls, levees, and related structures to protect infrastructure.	$$-$$$
Set aside land to support future flood-proofing needs (e.g., berms, dikes, and retractable gates).	$$$
Implement or retrofit source control measures that address altered influent flow and quality at treatment plants.	$$-$$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs and/or dams.	$$-$$$

Ecosystem Changes	
Planning Strategies	
Study response of nearby wetlands to storm surge events.	$
Implement policies and procedures for post-flood and/or post-fire repairs.	$
Participate in community planning and regional collaborations related to climate change adaptation.	$-$$
Integrate climate-related risks into capital improvement plans, including options that provide resilience against current and potential future sea-level and storm surge risks.	$
Ensure that emergency response plans deal with flooding and wildfire and include stakeholder engagement and communication.	$
Develop coastal restoration plans, including consideration of barrier islands, coastal wetlands, and dune ecosystems.	$-$$
Conduct climate change impacts and adaptation training for personnel.	$
Adopt insurance mechanisms and other financial instruments, such as catastrophe bonds, to protect against financial losses associated with infrastructure losses.	$
Plan for alternative power supplies to support operations in case of loss of power.	$
Develop models to understand potential water quality changes (e.g., increased turbidity) and costs of resultant changes in treatment.	$
Conduct sea-level rise and storm surge modeling. Incorporate resulting inundation mapping and frequency estimates into land use and facility planning.	$
Update fire models and fire management plans to incorporate any changes in fire frequency, magnitude and extent due to projected future climate conditions.	$-$$
Operational Strategies	
Practice fire management plans in the watershed, such as mechanical thinning, weed control, selective harvesting, controlled burns and creation of fire breaks.	$-$$
Monitor vegetation changes in watersheds.	$
Monitor surface water conditions, including streamflow and water quality.	$
Monitor flood events and drivers that may impact flood and water quality models (e.g., precipitation, catchment runoff, storm intensity, sea level).	$
Monitor current weather conditions, including precipitation and temperature.	$
Monitor and inspect the integrity of existing infrastructure.	$-$$
Capital / Infrastructure Strategies	
Acquire and manage coastal ecosystems, such as coastal wetlands, to attenuate storm surge and reduce coastal flooding ("soft protection").	$$$
Increase treatment capabilities to address water quality changes (e.g., increased turbidity or salinity).	$$$
Implement barriers and aquifer recharge to limit effects of saltwater intrusion. Consider use of reclaimed water to create saltwater intrusion barriers.	$$$
Relocate facilities (e.g., treatment plants) to higher ground.	$$$
Establish alternative power supplies, potentially through on-site generation, to support operations in case of loss of power.	$-$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs and/or dams.	$$-$$$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Diversify options to complement current water supply, including recycled water, desalination, conjunctive use, and stormwater capture.	$$$
Build flood barriers, sea walls, levees, and related structures to protect infrastructure.	$$-$$$
Implement or retrofit source control measures that address altered influent flow and quality at treatment plants.	$$-$$$
Set aside land to support future flood-proofing needs (e.g., berms, dikes, and retractable gates).	$$$
Acquire and manage ecosystems, such as forested watersheds, vegetation strips, and wetlands, to buffer against floods and sediment and nutrient inflows into source waterways.	$$$

Service Demand and Use	
Planning Strategies	
Update drought contingency plans.	$
Model or understand existing models of regional electricity demand under future scenarios of climate change and regional growth.	$
Model agricultural water demand under future scenarios of climate change and projections of cropping types. Consider evaluating the use of recycled water for irrigation.	$-$$
Work with power companies to evaluate feasibility of using recycled water or alternative cooling	$
Establish a relationship with the local power utility and work jointly on strategies to reduce seasonal or peak water and energy demands (e.g., water reclamation for use in power generation).	$
Operational Strategies	
Monitor current weather conditions, including precipitation and temperature.	$
Practice water conservation and demand management through water metering, rebates for water conserving appliances/toilets and/or rainwater harvesting tanks.	$-$$
Practice demand management through communication to public on water conservation actions.	$
Reduce agricultural and irrigation water demand by working with irrigators to install advanced equipment (e.g., drip or other micro-irrigation systems with weather-linked controls).	$$-$$$
Practice conjunctive use (i.e., optimal use of surface and groundwater).	$$-$$$
Optimize operations by restricting some energy-intensive activities during the summer to times of reduced electricity demand (i.e., nighttime) and work with energy utility on off-peak pricing.	$$-$$$
Improve energy efficiency of operations (e.g., installing more energy efficient pumps).	$$-$$$
Finance and facilitate systems to recycle water, including use of greywater in homes and businesses.	$$-$$$
Monitor surface water conditions, including streamflow and water quality.	$
Monitor surface water conditions, including water quality in receiving bodies.	$
Capital / Infrastructure Strategies	
Acquire and manage ecosystems, such as forested watersheds, vegetation strips, and wetlands, to buffer against floods and sediment and nutrient inflows into source waterways.	$$$
Build systems to reclaim wastewater for energy, industrial, agricultural, or household use.	$$$
Build or expand infrastructure to support conjunctive use.	$$$
Retrofit intakes to accommodate decreased source water flows or reservior levels.	$$-$$$
Increase treatment capabilities to address water quality changes (e.g., increased turbidity).	$$$
Establish alternative power supply via on-site power sources.	$-$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs and/or dams.	$$-$$$
Expand current resources by developing regional water connections to allow for water trading in times of service disruption or shortage.	$$-$$$
Diversify options to complement current water supply to include those that require less energy for treatment, conveyance, and distribution.	$$$
Build infrastructure needed for aquifer storage and recovery, (either for seasonal storage or longer-term water banking), (e.g., recharge canals, recovery wells).	$$$



December 2012

SafeWater RI

ENSURING SAFE WATER FOR RHODE ISLAND'S FUTURE

Phase 2 Report
Assessment of Impacts

Prepared for:

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RHODE ISLAND DEPARTMENT OF HEALTH

TETRA TECH

*Safe***Water** RI: Phase 2 Report *Executive Summary*

Drinking water utilities in Rhode Island face numerous challenges such as drought, pollution, competing water uses, and aging infrastructure that must be addressed to ensure that their customers receive safe, dependable, drinking water. The impacts from global climate change will exacerbate current challenges and present new risks to Rhode Island water utilities and their service areas.

To help respond to these challenges, the Rhode Island Department of Health (HEALTH), Office of Drinking Water Quality, launched *Safe***Water** RI*: Ensuring Safe Water for Rhode Island's Future (Safe***Water** RI*)*. The project will help address the implications of climate change on drinking water utilities by providing locally relevant and actionable data for water utility managers to evaluate and use to plan for future scenarios. The objectives of the project are to assess changing environmental conditions and their potential impacts on drinking water utilities in Rhode Island and develop strategies to address these changing conditions. The *Safe***Water** RI project includes four project components:

- Phase 1: Data Collection
- Phase 2: Assessment of Impacts
- Phase 3: Development of Management Strategies
- Phase 4: Outreach and Education

This report presents the Phase 2 assessment process and findings. The objective of Phase 2 of the *Safe***Water** RI project is to assess changing environmental conditions (including temperature, precipitation patterns, sea-level rise, and storm surge) due to climate change and their potential impacts on drinking water utilities in Rhode Island. Established public-domain simulation models were used for each stage of this assessment to enable continued analysis by HEALTH or other stakeholders as new data become available and to run new scenarios. This executive summary provides an overview of the risk assessment approach used for the project and the assessment findings.

APPROACH

Phase 2 consisted of three sequential levels of assessment: (1) a climate change assessment, including hydrologic change; (2) a future hazards assessment, which involved modeling projections of population, drought, riverine flood, coastal flood, sea-level inundation, and hurricane risk; and (3) a water utility infrastructure impact assessment, including structural damage estimates from each hazard. Figure 1 illustrates the Phase 2 risk assessment process. The italicized numbers correspond to the sections within the body of the document that describes the analysis.

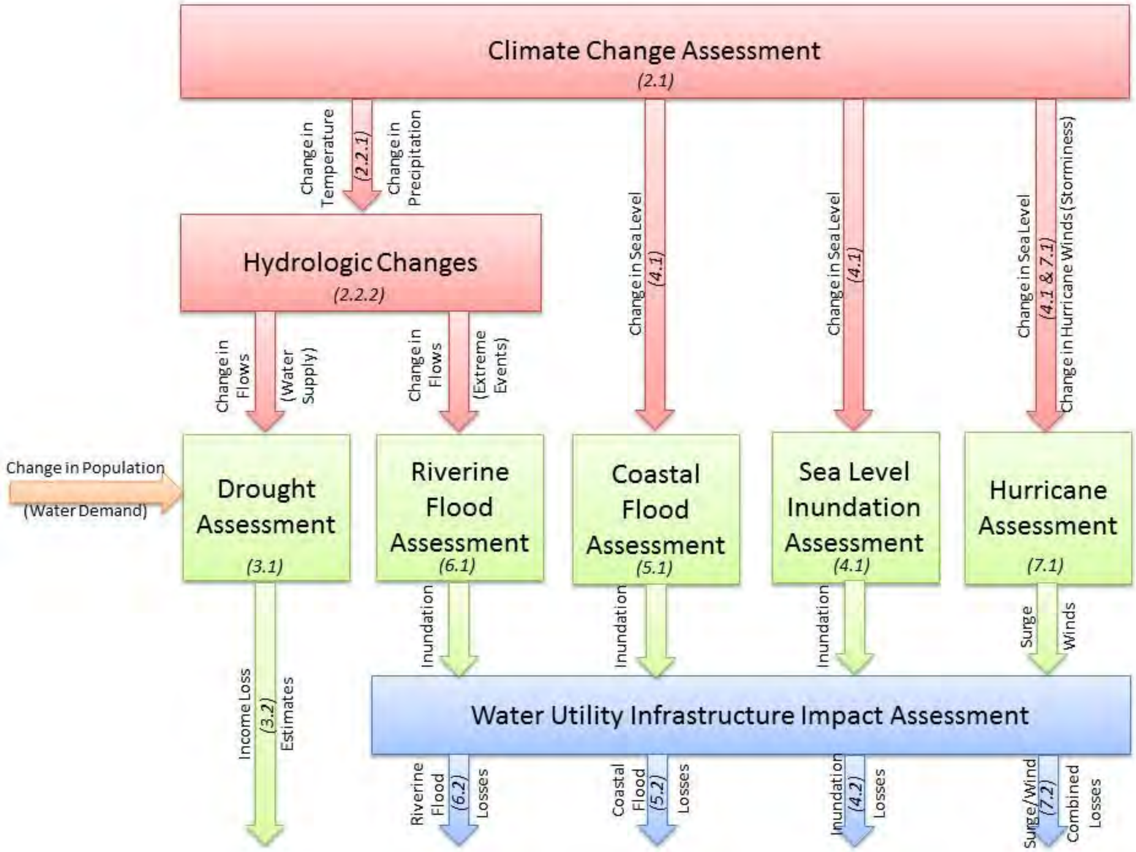

Figure 1. Phase 2 risk assessment process diagram.

The methodology used for each of the components of the three Phase 2 assessment levels is summarized below, including identification of methods, sites, models, and scenarios.

Climate Change Assessment Approach

- *Temperature and precipitation projections*—Projected temperature and precipitation time series data for Rhode Island were obtained from four Global Climate Models, across three future time horizons (2022, 2052, and 2084), and two greenhouse gas emissions scenarios (A2 and B1). These future climate inputs were used in hydrologic modeling of the Pawtuxet River Basin to evaluate the range of watershed responses to climate change that are likely to occur in Rhode Island.
- *Watershed hydrology*—Changes in surface water flows in response to future climate were investigated in detail for the Pawtuxet River Basin, which contains the Scituate Reservoir, the water source of the city of Providence. The Soil and Water Assessment Tool watershed simulation model was calibrated to represent observed hydrology. The model was then run with future climate precipitation and temperature time series data to evaluate the full range of high- and low-flow responses.
- *Sea-level rise projections*—A low and high sea level elevation for each time horizon was calculated using local National Oceanic and Atmospheric Administration gauge station data and a probabilistic methodology developed by the U.S. Environmental Protection Agency.

Hazards Assessment Approach

- *Water demand*—Future water demand was evaluated using projections of future population on the basis of U.S. Census data for the three time horizons.
- *Drought assessment*—A drought hazard analysis was conducted using the watershed model output for the three time horizons.
- *Riverine flood assessment*—Hazards due to changes in frequency and magnitude of inland flooding were evaluated using the results of the watershed modeling and the Federal Emergency Management Agency's (FEMA's) HAZUS-MH software.
- *Sea-level inundation assessment*—Sea-level rise projections were used to estimate future coastal inundation and associated hazards to infrastructure.
- *Coastal flood assessment*—The sea-level inundation analysis was combined with wave runup and erosion analysis using FEMA's HAZUS-MH software to evaluate the hazards of coastal flooding for the three time horizons.
- *Hurricane assessment*—Hurricane storm surge and wind hazards for future climate conditions were modeled using FEMA's HAZUS-MH software.

Water Utility Infrastructure Impact Assessment Approach

- *Drought loss assessment*—Simulated future water supply from surface flow was compared with the future water demand to assess impacts from drought.
- *Riverine flood loss*—Direct infrastructure impacts from flood inundation were assessed in the HAZUS-MH software for the three time horizons.
- *Sea-level inundation loss*—Infrastructure at risk of being permanently submerged by sea-level rise was identified.
- *Coastal flood loss*—HAZUS-MH software was used to assess direct infrastructure impacts from flood inundation for the three time horizons.
- *Storm surge and wind loss*—Direct damages from storm surge inundation and wind (e.g., from hurricanes) were assessed in the HAZUS-MH software for the three time horizons.

FINDINGS

The conclusions of the Phase 2 study are presented below for the Rhode Island water utilities. On the basis of the assessments conducted, several Rhode Island drinking water utilities could be adversely affected by climate change, including possible significant infrastructure losses of water treatment plants, pump stations, pipelines, wells, booster stations, and interconnections.

Climate Change Assessment Results

- *Temperature*—Global climate models are in agreement that average air temperatures will increase continuously over the next century. ***By 2084, average annual temperature is expected to have increased by about 4 to 5 degrees Celsius.***
- *Precipitation*—Global climate models are not in agreement as to whether annual average precipitation will increase or decrease over Rhode Island; however, many of the climate models suggest slightly higher annual precipitation by 2084***. More extreme precipitation events are anticipated for the future***.
- *Hydrologic cycle*—Surface water supplies reflect a balance between precipitation and evaporation. Evaporation will increase with increasing temperature, but it is balanced by

increasing precipitation in many of the climate scenarios modeled. For a majority of the scenarios, an ***increase is expected in the total average annual flow volume over each of the future time horizons***.

Hazards and Water Utility Infrastructure Impact Assessment Results

- *Drought*—Historical data show that a major drought lasting 3 years can reduce the drought flow to 70 percent of normal flow. While most of the watershed simulations for future climate scenarios show an increase in average annual flow volume, several of the climate scenarios predict decreases in summer flows. With climate change potentially reducing some surface water flows by as much as 18 percent, ***droughts would become more intense***. Furthermore, an increase in water demand is expected as the population grows by an average of 14 percent by 2022, 50 percent by 2052, and 88 percent by 2084. To date, the water utilities in Rhode Island have been able to compensate for drought periods by using interconnections to share the water supply and by imposing water restrictions. But with additional demand and a reduced flow, significant economic and social impacts could result (e.g., decreased water availability for agricultural activities).
- *Sea-level rise impacts*—The model results show that ***36 water utilities would be adversely affected by sea-level rise***. The Bristol County Water Authority and the Westerly Water Department would incur more than $10 million each in pipeline losses. Newport Water Works, United Water Rhode Island, South Kingstown Water Department, and Narragansett Water Department would lose booster pump stations and interconnections. These losses assume that no adaptation efforts would be taken in the coming years. The total losses range from $22.3 million for 2022, $27.5 million for 2052, $39.7 million for 2084, and $87.5 million for the 5-foot sea-level rise estimate.[1]
- *Coastal flooding*—Modeled results show that ***major infrastructure is at risk*** for the Bristol County Water Authority (potential impacts up to $2.68 million), Jamestown Water Division (refer to Figure 2; potential impacts up to $12.8 million), and Newport Water Works (potential impacts up to $4.4 million). At-risk infrastructure includes three water treatment plants in the existing coastal floodplain. ***This infrastructure is now at risk, and that risk is expected to increase significantly for future periods***.
- *Riverine flooding*—Model results show that ***numerous wells, booster stations, and interconnections are at risk, owned by several utilities***. The Rhode Island Economic Development Corporation has the highest loss estimate ($1.29 million), primarily because of the likelihood for well inundation, potentially by up to 16 feet of water, and the

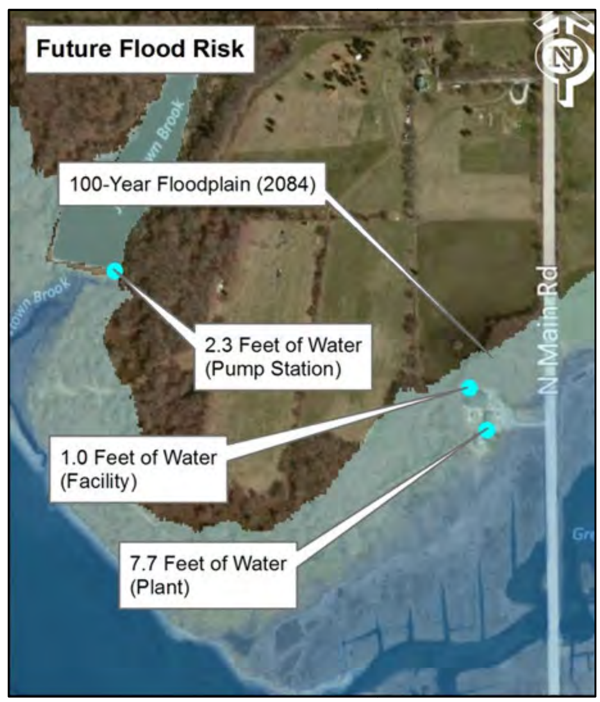

Figure 2. Jamestown Water Division, future flood risk.

[1] The Rhode Island Coastal Resources Management Program (CRMP) has begun to integrate a sea-level rise of between 3 to 5 feet (CRMP 2008) in its plans and policies. Five feet is greater than the 2084 high scenario for either Providence (2.80 feet) or Newport (2.92 feet) and was integrated into this study's analysis to represent the most conservative value (worst case) for sea-level rise.

location of several pump stations in the floodplain. Many of these potential impacts could occur soon (within the 2022 period), which is well within the infrastructures' lifespan.

- *Hurricane*—Future climate will bring sea-level rise with the potential for more powerful tropical storms. Modeled results show that ***all water utilities' infrastructure would be affected by wind from a powerful hurricane, while 12 utilities would also be affected by the storm surge***. Three water treatment plants would be substantially damaged from a hurricane. These water utilities are projected to have the greatest losses: Jamestown Water Division (potential impacts up to $20.4 million), Newport Water Works (potential impacts up to $6.8 million), and Bristol County Water Authority (potential impacts up to $4.3 million).

NEXT STEPS

The *Safe***Water** RI project is iterative, with each phase building on the previous phase(s). The Phase 1 data collection efforts have established a baseline of understanding of the viewpoints and activities of water utility partners; the Phase 2 impact assessment has identified the priority vulnerabilities and risks to water utility infrastructure. Both phases will be used to inform the remaining *Safe***Water** RI project phases. For example, identifying priority issues and key challenges of the water utilities in Phase 2 will assist in developing appropriate adaptation options (Phase 3: Development of Management Strategies), while understanding the utility stakeholder perceptions of climate change and extreme weather will assist in developing education and outreach strategies (Phase 4: Outreach and Education). Developing and maintaining relationships with the water utility partners will also assist in facilitating the ultimate *buy-in* for project recommendations.

Given the need to plan for climate change in the face of a number of uncertainties, Phase 3 will focus on management strategies that build on, or align with, other water system issues: natural hazard, economic, social, or environmental. Challenges in these areas (e.g., increasing demand for water, sea-level rise/erosion, development in areas with high-risk water systems) can be exacerbated by the climate change impacts identified in this study. Tackling high-priority challenges using management strategies with multiple benefits supports planning for the future in a way that is beneficial regardless of whether the anticipated climate change affects drinking water utility assets as modeled.

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*Safe*Water RI: Phase 2 Report

1.0 BACKGROUND AND OVERVIEW

Drinking water utilities in Rhode Island face numerous challenges such as drought, pollution, competing water uses, and aging infrastructure that must be addressed to ensure that their customers receive safe, dependable drinking water. The potential impacts from global climate change could exacerbate current challenges and present new risks to Rhode Island water utilities and their service areas.

Altered precipitation patterns could increase flood events, like the recent flooding experienced in 2010; more extreme weather events could pose storm surge risks to the state's more than 400 miles of coastline. In addition to physical damage to water infrastructure systems and dams, flooding can also increase turbidity and pollutant loads in source water, requiring more extensive treatment to remove the pollutants. Excessive flooding can also release pathogens from storm sewer systems when their capacity to manage wastewater is exceeded during storm events. Areas that rely heavily on wells, such as the eastern portion of the state, could become contaminated by surface water containing pathogenic protozoa such as *Giardia* and *Cryptosporidium*. Additionally, the global melting of glaciers and ice sheets, coupled with the thermal expansion of ocean volume as water temperatures increase, will affect coastal areas through sea-level rise. The elevated sea levels can contaminate aquifers through intrusion of saltwater and damage coastal ecosystems, which will be particularly challenging for Rhode Island because the majority of the population lives along the coastline.

To help respond to these challenges, the Rhode Island Department of Health (HEALTH), Office of Drinking Water Quality, launched *Safe***Water** RI*: Ensuring Safe Water for Rhode Island's Future* (*Safe***Water** RI) in January 2012. The project will help address the implications of climate change for drinking water utilities by providing locally relevant and actionable data for water utility managers to evaluate and plan for future scenarios. The objectives of the project is to assess changing environmental conditions (including temperature, precipitation patterns, sea-level rise, and storm surge) and their potential impacts on drinking water utilities in Rhode Island to develop strategies to address such changing conditions. The *Safe***Water** RI project has four project components:

- Phase 1: Data Collection
- Phase 2: Assessment of Impacts
- Phase 3: Development of Management Strategies
- Phase 4: Outreach and Education

This report summarizes the methodology and findings of phase 2 of the *Safe***Water** RI project. Phase 2: Assessment of Impacts activities included assessing how climate will change over three time horizons (2022, 2052, and 2082) and how these changes could exacerbate and create drought, sea-level rise, coastal flooding, riverine flooding, and hurricane hazards. This report provides HEALTH with a summary of project activities to date and helps identify areas of concern. Phase 2 results will also be used to inform the remaining *Safe***Water** RI project phases. Established public-domain simulation models were used for each stage of this assessment to enable continued analysis by HEALTH or other stakeholders as new data become available and to run new scenarios.

The Phase 2 report is organized according to the following:

- Section 1: Introduction
- Section 2: Climate change assessment methodology and results

- Sections 3–7: Hazard-specific assessment and infrastructure impact
- Section 8: Next steps

Figure 1 is a process diagram for the Phase 2 risk assessment process, and it provides italicized section numbers that correspond to each step of the assessment process.

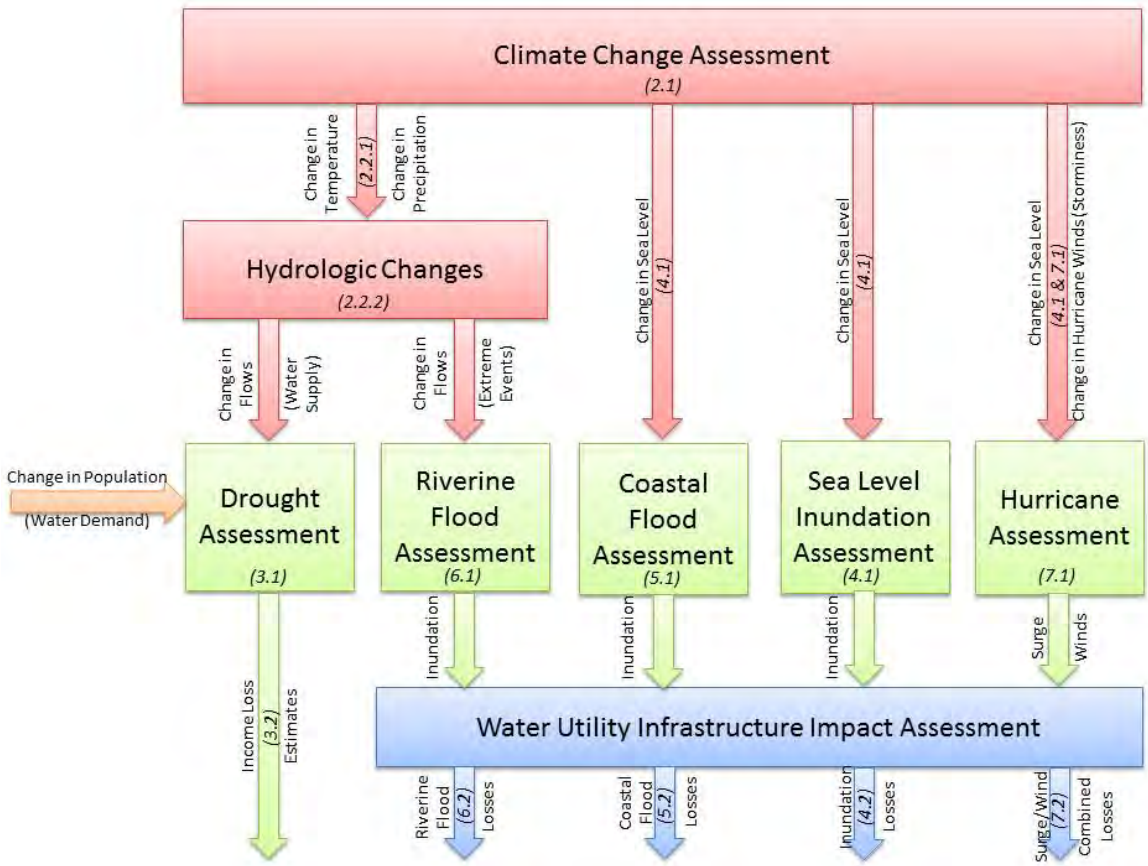


Figure 1. Phase 2 process diagram.

For Sections 3-7 an overview of the impact from each hazard (drought, riverine flood, coastal flood, sea level inundation, and hurricane) is assessed specific to the service areas for each utility. Figure 2 illustrates the location and service area of each utility considered in this report.

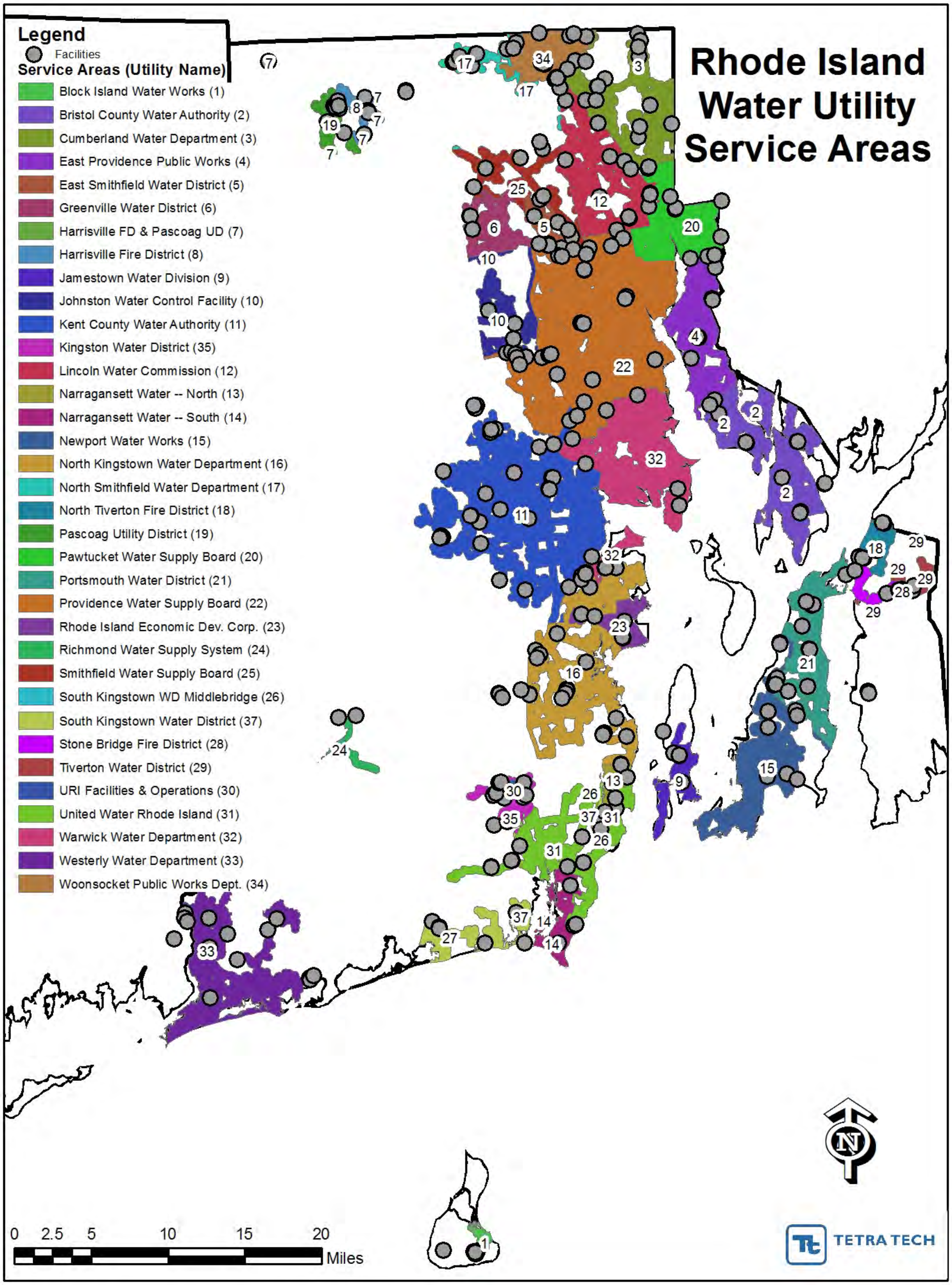


Figure 2. Water Utility Service and Facility Map.

2.0 CLIMATE CHANGE ASSESSMENT

The project's approach evaluates responses to potential future climates, using Global Climate Models (GCMs), combined with projections of future greenhouse gas (GHG) concentrations as summarized in the *Special Report on Emission Scenarios* (Nakicenovic et al. 2000). These simulation models estimate future temperature and precipitation conditions. These conditions are then used to project water supply and extreme flood events. Economic impacts are then evaluated to characterize potential climate change risks to the Rhode Island Water Utilities.

There are many uncertainties related to current understanding of the physical climate system and future GHG emissions. It is beyond current modeling capabilities to accurately predict climate changes at the watershed level (Johnson et al. 2012). However, using an approach that evaluates a number of scientifically plausible future states allows an assessment of the sensitivity of the system. Thus, the goal of the climate change assessment is not to determine the single, *most likely* future trajectory of the watershed, but instead to better understand the sensitivity of the Pawtuxet watershed to climate change. For this project, 24 scenarios were identified for evaluation. The 24 scenarios are based on four GCMs, which were applied to three periods (2022, 2052, and 2084) and under two different emission scenarios (A2 and B1).

2.1 Methodology

This section presents the methodology used to modify the climate time series for the Rhode Island watershed and summarizes the results of the climate change assessment. GCMs provide climate information at a scale (approximately 1 degree of latitude) that is too coarse for use in watershed modeling. In addition, many GCMs display well-documented biases with regard to precipitation frequency and intensity. Specifically, GCMs tend to generate too many low-intensity events and under-simulate the intensity of large events (Sun et al. 2006; Dai 2006). These problems can be addressed by downscaling the GCM output to a smaller spatial scale and by implementing the GCM predictions using a delta method in which historical time series are modified to reflect the relative changes in precipitation and temperature predicted by the GCM. This ensures that the resulting meteorological series are physically realistic at the local scale of watersheds.

Climate scenario changes to the historic meteorological time-series were implemented using Bias-Corrected and Spatially Downscaled (BCSD) World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project Phase 3 (CMIP3) Climate Projections (BCSD statistically downscaled data). These data use statistical bias correction to interpret GCMs over a large spatial domain on the basis of current observations. The principal potential weakness of this approach is an assumption of stationarity. That is, the assumption is made that the relationship between large-scale precipitation and temperature and local precipitation and temperature in the future will be the same as in the past. Thus, the method can successfully account for orographic effects that are observed in current data, but not for impacts that might result from the interaction of changed wind direction and orographic effects. A second assumption included in the bias-correction step of the BCSD method is that any biases exhibited by a GCM for the historical period will also be exhibited in simulations of future periods.

The methodology used to modify the existing time-series included the following broad steps:

- Download and calculate monthly change statistics relative to historical data from the CMIP3 BCSD data sets for temperature and precipitation.
- Use the Climate Assessment Tool (CAT; USEPA 2009) to modify the precipitation and temperature time-series in the existing Watershed Data Management (WDM) file using seasonal multipliers to generate the Soil and Water Assessment Tool (SWAT) input precipitation and temperature time series files. USEPA's Better Assessment Science Integrating point & Non-point Sources (BASINS) CAT facilitates watershed-based assessments of the potential effects of

climate variability and change on water and watershed systems (namely streamflow and pollutant loads). A WDM file is a binary file used to store data external to a watershed (weather forcing, point source data, and such).

- Assume other meteorological variables (wind, humidity, solar radiation) remain unchanged at current levels and can be represented by SWAT's statistical weather generator, which incorporates monthly distribution statistics for a variety of Rhode Island stations.
- Use SWAT's built-in simulation of the full Penman-Monteith energy balance method for estimating potential evapotranspiration (PET)—a measure of the energy available to evaporate water and transpire water through plants.
- Assign future carbon dioxide (CO_2) concentrations appropriate to the time frame and emission storyline. This is important because SWAT includes an integrated plant growth model, and elevated CO_2 concentrations enable many plants to obtain the CO_2 they need for photosynthesis with shorter periods of stomatal opening and, thus, reduced water loss.

2.1.1 BCSD WRCP CMIPS Scenario Data Download and Calculations

The climate projection archive at <http://gdo-dcp.ucllnl.org> includes data sets representing three scenarios or *storylines* for future GHG emissions forcing global climate change, as defined in Nakicenovic et al. (2000). Sixteen CMIP3 models are available under each emission scenario with each model having one or more simulations consisting of unique initial conditions or runs.[1] Four GCMs under two emission pathways were selected for this project's analysis. The A2 and B1 emission storylines were selected because they represent a range of higher and lower GHG emissions scenario.[2] The GCM models selected for this project were CGCM3, GFDL, CCSM3, and HadCM3. They were selected on the basis of their international recognition and use and because they provided higher data availability from other GCMs. The selected emission pathways, GCMs, and run numbers (index of the model run in the climate data archive) are shown in Table 1.

Table 1. Selected GCM models, emission pathways, and projection run numbers

		BCSD CMIP3 climate and hydrologic projections	
Modeling group, country	WCRP CMIP3 I.D.	SRES A2 run #	SRES B1 run #
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)	4	4
U.S. Department of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0	1	1
National Center for Atmospheric Research, USA	CCSM3	4	4
Hadley Centre for Climate Prediction and Research/ Met Office, United Kingdom	UKMO-HadCM3	1	1

Source: Nakicenovic et al. 2000
Notes: NOAA = National Oceanic and Atmospheric Administration; WCRP = World Climate Research Program; CMIP3 = Coupled Model Intercomparison Project phase 3; BCSD = Bias-Corrected and Spatially Downscaled; SRES = Special Report on Emissions Scenarios

[1] For more information on the World Climate Research Programme Coupled Model Intercomparison Project Phase 3, see http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-1.html.
[2] The A2 emission scenario assumes a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. The B1 scenario family is near the lower limit of projected changes in greenhouse gas emissions. The B1 scenario assumes global population growth peaks by mid-century and then declines, a rapid economic shift toward service and information economies, and the introduction of clean and resource-efficient technologies. For more information on emission scenarios, see the IPCC website http://sedac.ipcc-data.org/ddc/sres/index.html.

The BCSD-CMIP3 climate projections for each GCM model include the following variables:

- Monthly mean surface air temperature (°C)
- Mean daily precipitation rate during each month (millimeter per day [mm/day]). Note that precipitation bin-intensity data are not available for the BCSD-CMIP3 scenarios.

The BCSD-CMIP3 climate projections are available at a resolution of 1/8° latitude-longitude (~12 kilometer [km] by 12 km); this provides a grid of data points over the Pawtuxet River watershed study area. The available time series output covers a 150-year period from 1950 through 2099. This provides a basis for calculating statistics on historical data and change statistics for future periods. The four meteorological stations used in the watershed model setup (see Section 2.1.3) and the BCSD data grid cell centroids in the vicinity of the study area are shown in Figure 3.

Current baseline conditions are represented by a 30-year period from 1978 through 2007. The observed time series were then modified using the delta method, as described below, to create comparable 30-year time series for future time horizons. A 30-year basis was selected to provide a good representation of the natural variability and decadal oscillations in the climate and hydrology of the watershed. The three future time horizons centered on 2022, 2052, and 2084 were compared to the base period to modify the weather time series as follows:

- Time Horizon 1 centered at 2022: Compare 2008-2037 to 1978-2007
- Time Horizon 2 centered at 2052: Compare 2038-2067 to 1978-2007
- Time Horizon 3 centered at 2084: Compare 2070-2099 to 1978-2007

A total of 24 scenarios were identified according to four GCMs applied to three periods and under two emission scenarios (A2 and B1). Multiyear averages were first calculated for each time slice including the base or current period. For each GCM and time horizon, monthly deltas and percent change statistics were calculated for surface air temperature and precipitation using the multiyear, monthly average values. The deltas were calculated as the future minus the current, and the percent change was calculated as the delta divided by the current.

2.1.2 Application of CAT

The CAT (USEPA 2009), which is provided in the U.S. Environmental Protection Agency's (EPA's) BASINS modeling system, allows a number of iterative modifications to be applied to the precipitation and temperature time series to represent climate change.[3] CAT applies these changes (multiplier or additive delta) on a monthly, average, or seasonal basis. Within CAT, a series of operations for time-series adjustments can be applied in sequence and saved as a scenario.

To facilitate efficient procession of the time-series, an automated custom XML script was generated. The XML script accesses and processes the WDM file using a standalone CAT executable (BATCHCAT) that has the full functionality of CAT and can be applied outside the BASINS MapWindow environment. A Microsoft Excel application was used for running BATCHCAT this way. An XML batch file with seasonal modifications for each station's time-series data was also created.

The basic adjustment method for estimating projected temperatures is to apply a constant monthly additive delta value to current temperatures. The air temperature time-series were adjusted based on an additive change using the deltas (°C) calculated from the downloaded BCSD CMIP3 data.

[3] CAT provides flexible capabilities for creating climate change scenarios allowing users to quickly assess a wide range of what if questions about how weather and climate could affect their systems. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203460.

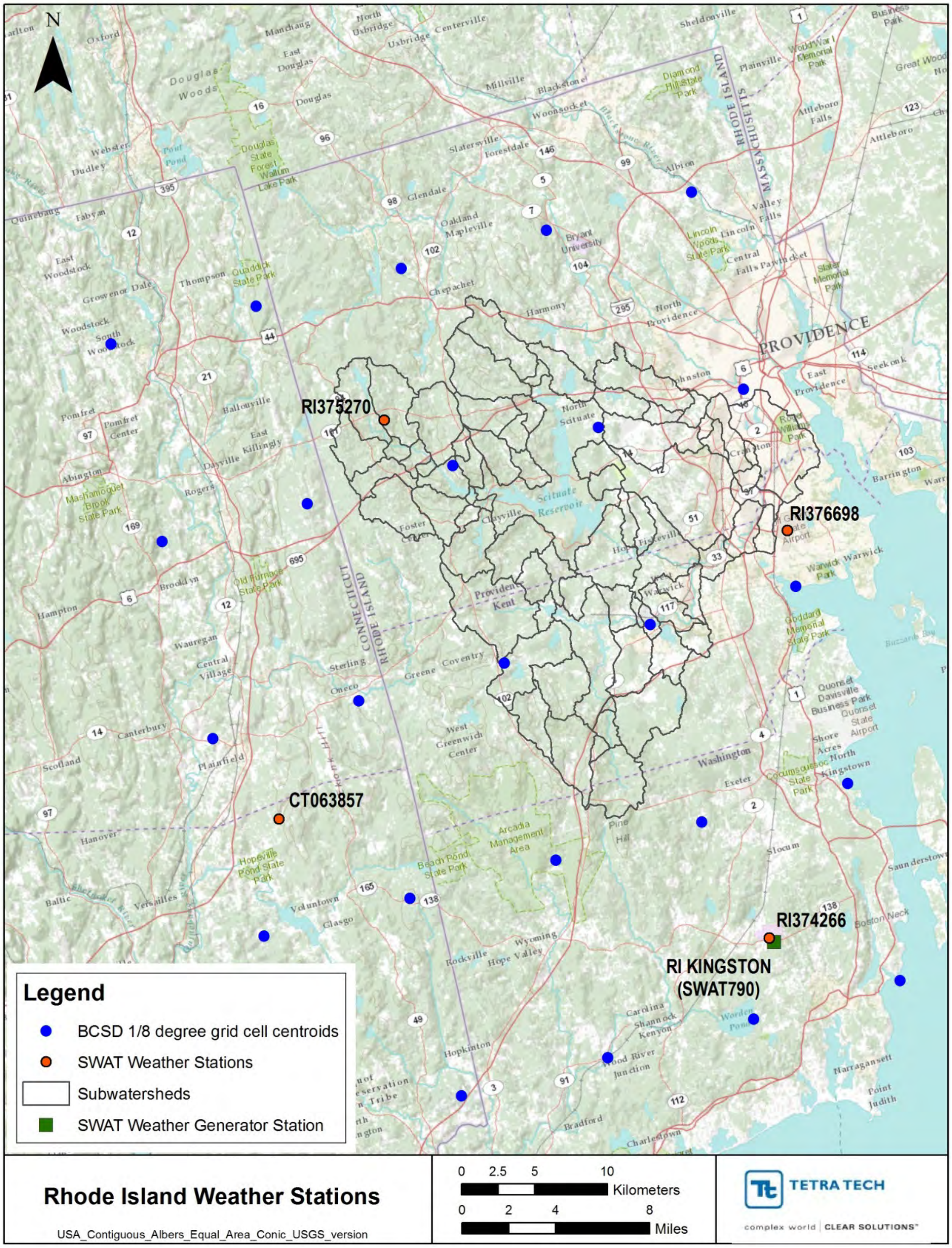


Figure 3. Pawtuxet River SWAT model weather stations and BCSD-CMIP3 grid cells.

In addition to changes in precipitation volume and timing, climate models suggest a general intensification of the global hydrologic cycle, with a greater proportion of precipitation occurring in high-intensity events (IPCC 2007; Karl et al. 2009). The CAT can represent precipitation intensification by focusing changes in precipitation volume in a user-specified event size class. Intensity changes to precipitation were applied on a monthly basis. Monthly multipliers based on percent change were developed for the scenarios to account for intensification by assuming that any increases in precipitation volume occur within the largest 30 percent of storm events, and the CAT was used to apply the multiplier to the base period precipitation time series. For both temperature and precipitation, modifications for each of the stations and their associated time-series data set number in the WDM were created (keeping the data set number identification [ID] the same as the existing condition) and applied in a batch mode.

Equations used to calculate future volumes of precipitation are presented below. The ratio of the total volume in a climate scenario (*V2*) relative to the baseline period scenario volume (V_1) was given as *r* (V_2/V_1). For the case when $r = V_2 / V_1 > 1$ (increasing precipitation), the future volume representing the climate scenario (V_2) can be defined as

$$V_2 = V_{1L} + r^* \cdot V_{1H} ,$$

where r^* is the change applied only to the upper range (> 30%)
V_H is the volume in the top 30%, and
V_L is the volume in the bottom 70%.

If we set $r^* = r + \cdot(r-1) \cdot V_{1L} / V_{1H}$ the overall change is satisfied, as

$$\mathrm{V}_2 = \mathrm{V}_{1L} + \mathrm{r}^* \cdot \mathrm{V}_{1H} = \mathrm{V}_{1L} + \mathrm{r} \cdot \mathrm{V}_{1H} - \mathrm{V}_{1L} + \mathrm{r} \cdot \mathrm{V}_{1L} = \mathrm{r}\,(\mathrm{V}_{1H} + \mathrm{V}_{1L}) = \mathrm{r} \cdot \mathrm{V}_1 .$$

Further, as $r > 1$, r^* is always positive.

For the case of $r <= 1$ (decreasing precipitation), an across-the-board decrease in precipitation was applied as follows

$$V_2 = r \cdot V_{1L} + r \cdot V_{1H}$$

The adjustment factors can then be assembled as

For the events above the 70th percentile, when

$r > 1$ then r^*
$r <= 1$ then r.

For the events below the 70th percentile, when

$r > 1$ then 1 (no change)
$r <= 1$ then r.

2.1.3 Converting Climate Forcing to Watershed Response

Watershed hydrology is largely determined by the interaction of precipitation and evapotranspiration (which is strongly dependent on temperature). Both precipitation and PET are expected to increase in Rhode Island under future climates, while the seasonal timing of precipitation inputs, and the plant growth cycle, is also expected to shift. Because of the interaction of these factors, it is difficult to predict climate response directly from the climate inputs. Instead, a simulation model is used to convert climate forcing to watershed response.

The hydrologic simulation model selected for this project is SWAT, (SWAT 2009, version 488). SWAT was developed by the U.S. Department of Agriculture to simulate the effect of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods (Neitsch et al. 2005; Neitsch et al. 2011). SWAT requires data inputs for weather, soils, topography, vegetation, and land use to model water and sediment movement, nutrient cycling, and numerous other watershed processes. It is a continuous model appropriate to long-term simulations and has been widely applied throughout the United States.

A key feature of SWAT is the incorporation of an explicit plant growth model, including plant interactions with water, temperature, and atmospheric CO_2 concentrations. This allows the model to explicitly simulate the feedback loops between climate and plant growth that determine soil moisture and hydrologic responses. Appendix A further describes development and calibration of a SWAT model for the Pawtuxet watershed.

2.2 Scenario Result Summaries

This section presents the results of the 24 scenarios (described in 2.1.1) evaluated to assess potential climate change impacts.

2.2.1 Precipitation and Temperature Changes

The scenario result summaries compare precipitation and temperature projections after applying the climate change statistics to baseline period data. These summaries are presented as box and whisker plots (Figures 4-9) and seasonal plots (Figures 10-15) for all weather stations. The box and whisker plots show the 25th percentile, median, and 75th percentile (the box), along with the range from the minimum to the maximum (the whiskers). The seasonal plots show the average for each month over the 30-year simulation. For each time horizon, the eight model-derived series are shown as lines, and the existing baseline condition is shown in the background as an area. Consistent with other areas of the country, the GCMs are in agreement in predicting increases in temperature throughout the year; however, they are often in disagreement as to whether average precipitation will increase or decrease for a given month.

The results also demonstrate that the A2 emission scenarios tend to predict more precipitation in the study area than the B1 emission scenarios (with the exception of CCSM 2052 and HadCM3 2022). The precipitation predictions tend to increase as the time horizon extends into the future and thermal energy increases. The HadCM3 scenario shows the highest variability from 2022 to 2084; CGCM3 shows the least variability.

Temperature predictions for all scenarios increase consistently with each time horizon. Annual average temperature increase for the 2084 scenarios was around 4.4 °C, whereas for the 2022 scenarios, it was around 1.1 °C. The GFDL scenarios tended to predict the highest increases across time horizons and A2 and B1 scenarios. The A2 scenarios always showed a higher temperature increase from the baseline condition for all scenarios.

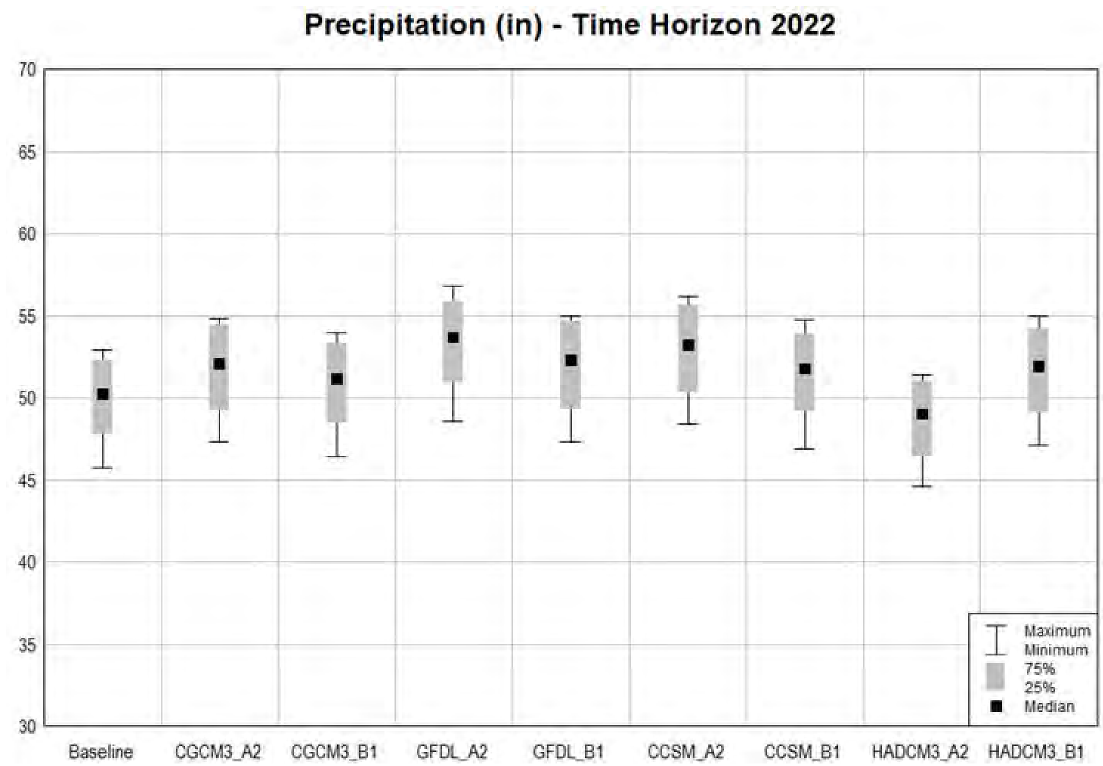


Figure 4. Modeled precipitation for 2022.

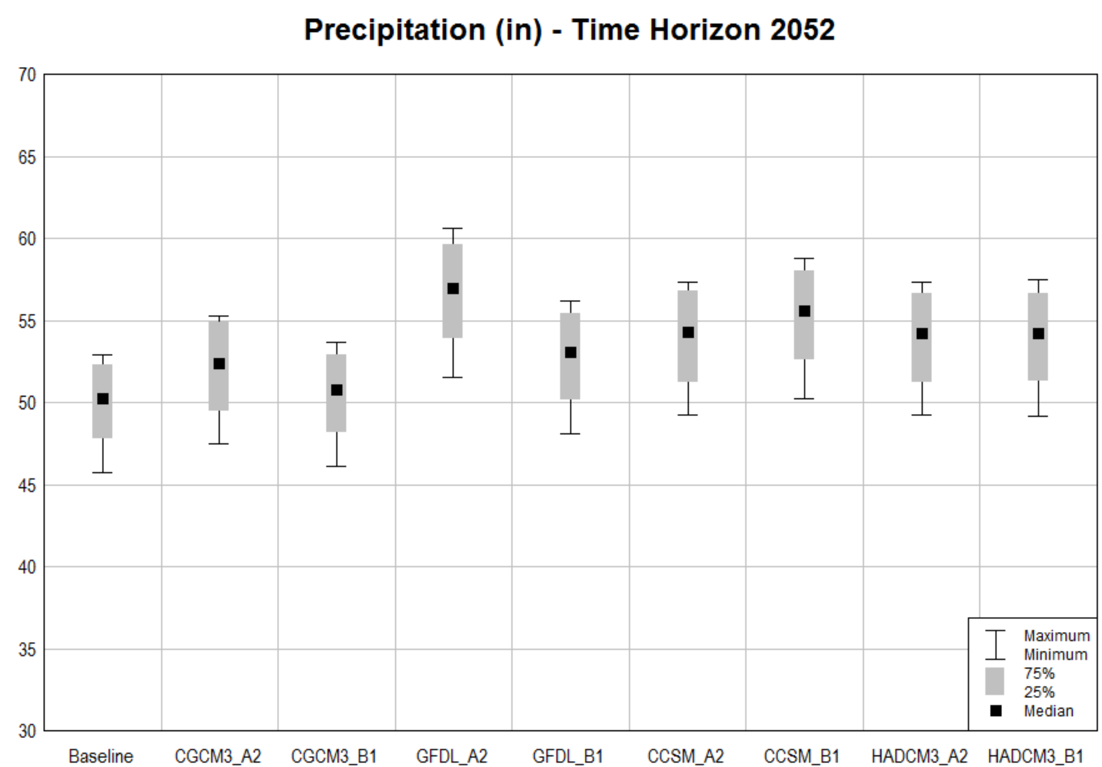


Figure 5. Modeled precipitation for 2052.

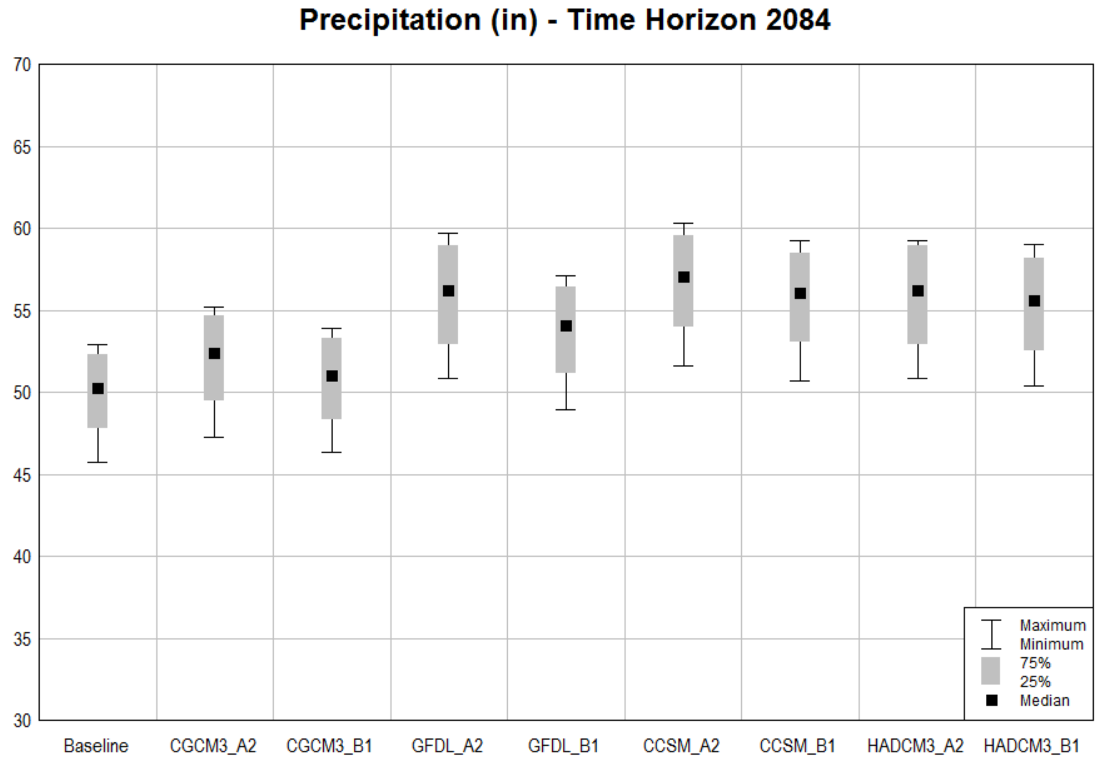


Figure 6. Modeled precipitation for 2084.

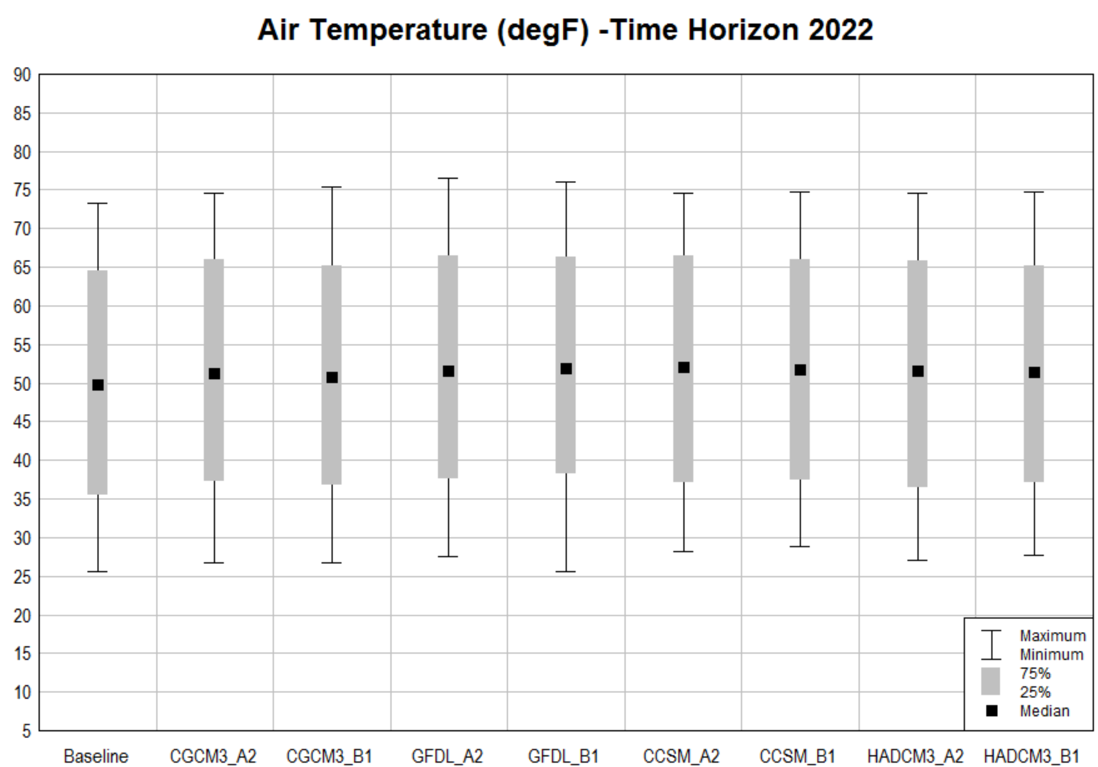


Figure 7. Modeled air temperature for 2022.

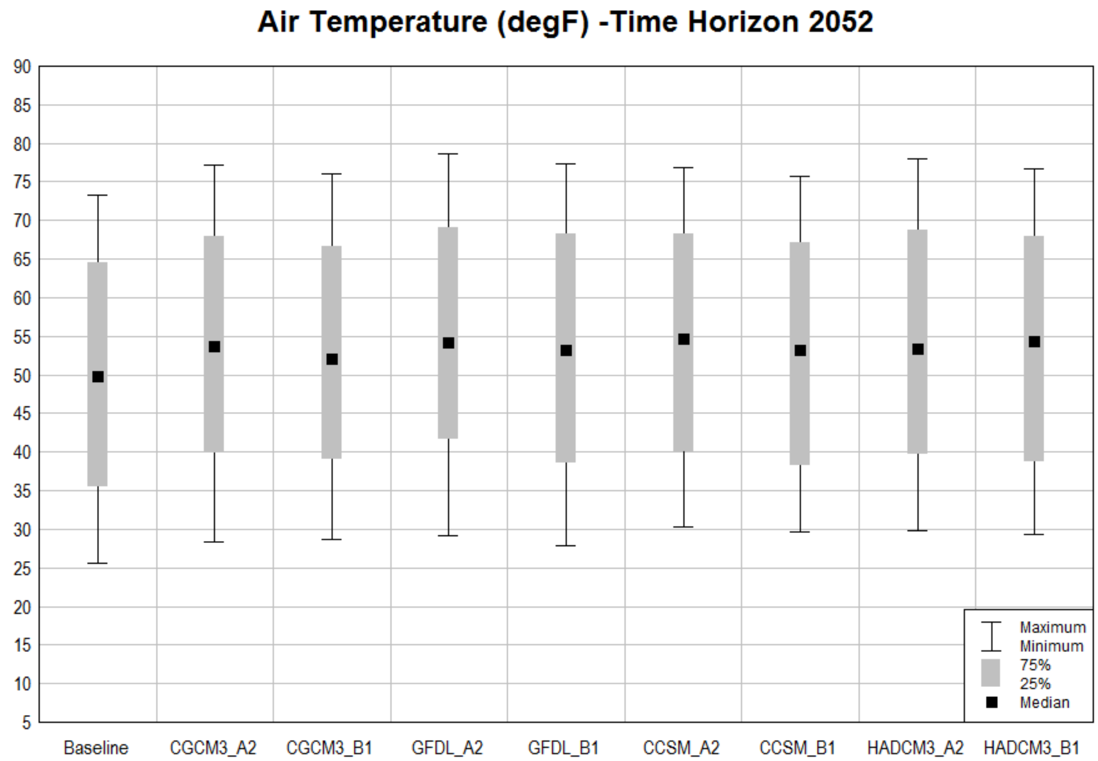


Figure 8. Modeled air temperature for 2052.

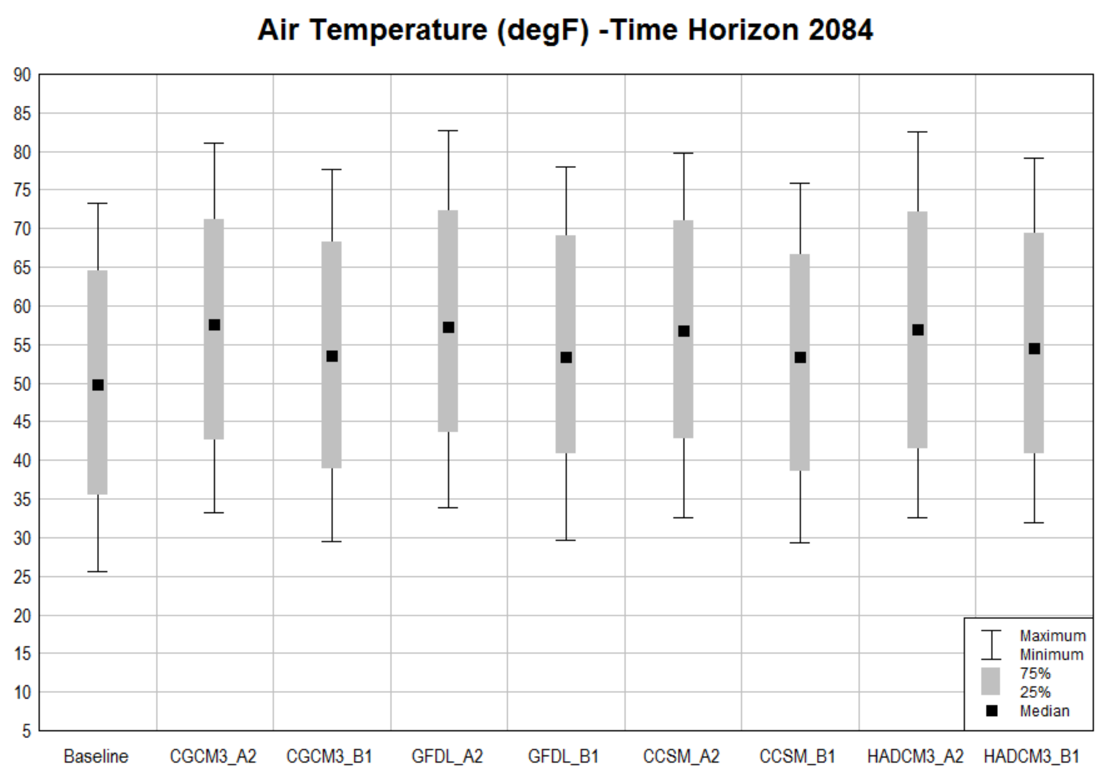


Figure 9. Modeled air temperature for 2084.

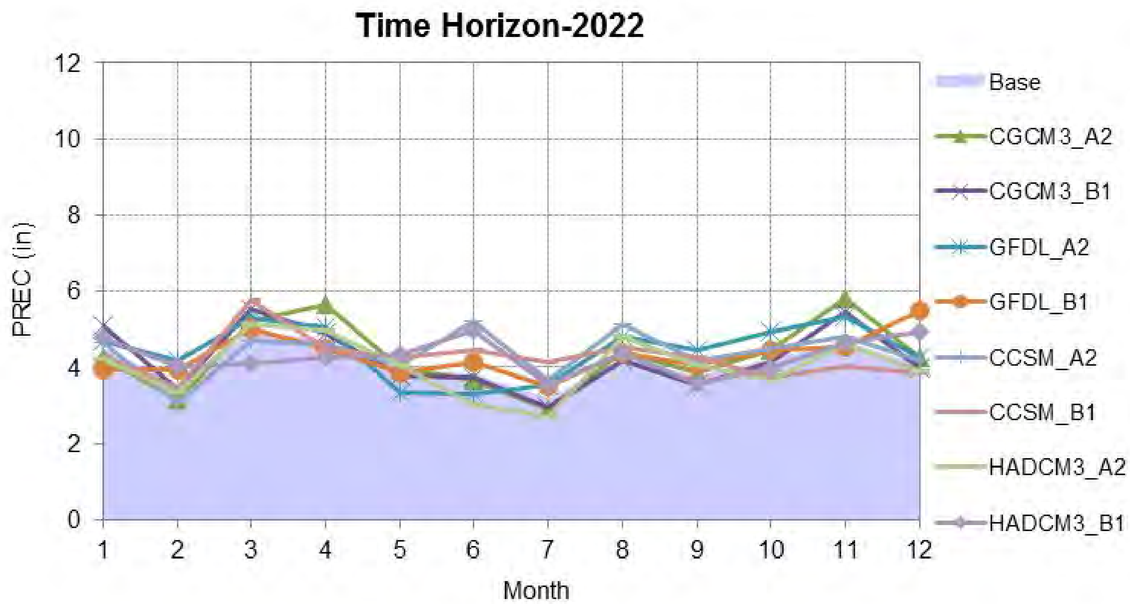


Figure 10. Monthly variation of modeled precipitation for 2022.

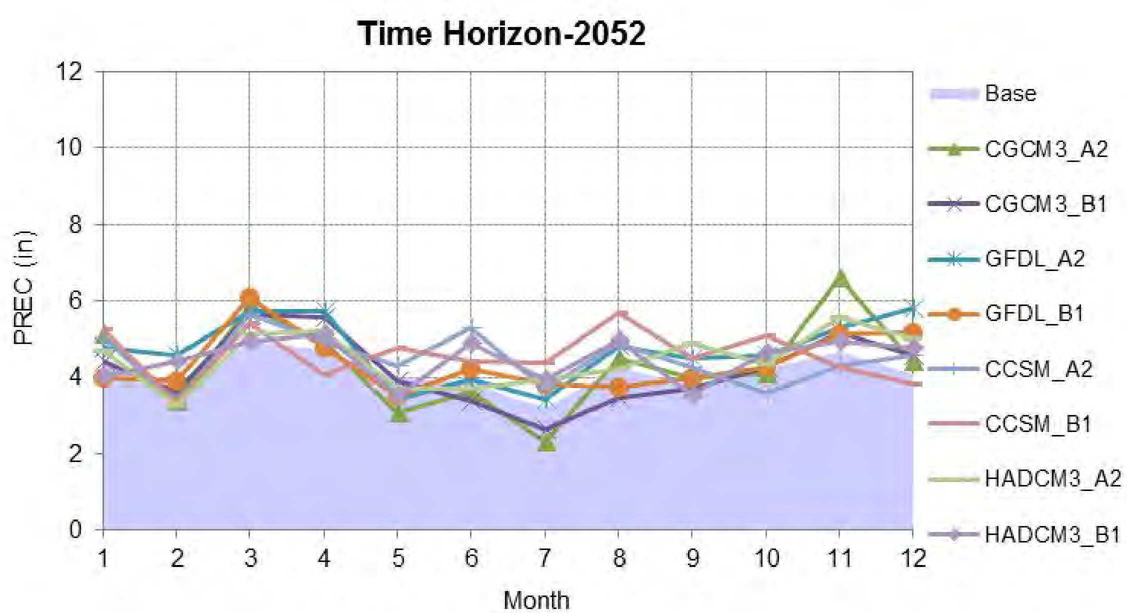


Figure 11. Monthly variation of modeled precipitation for 2052.

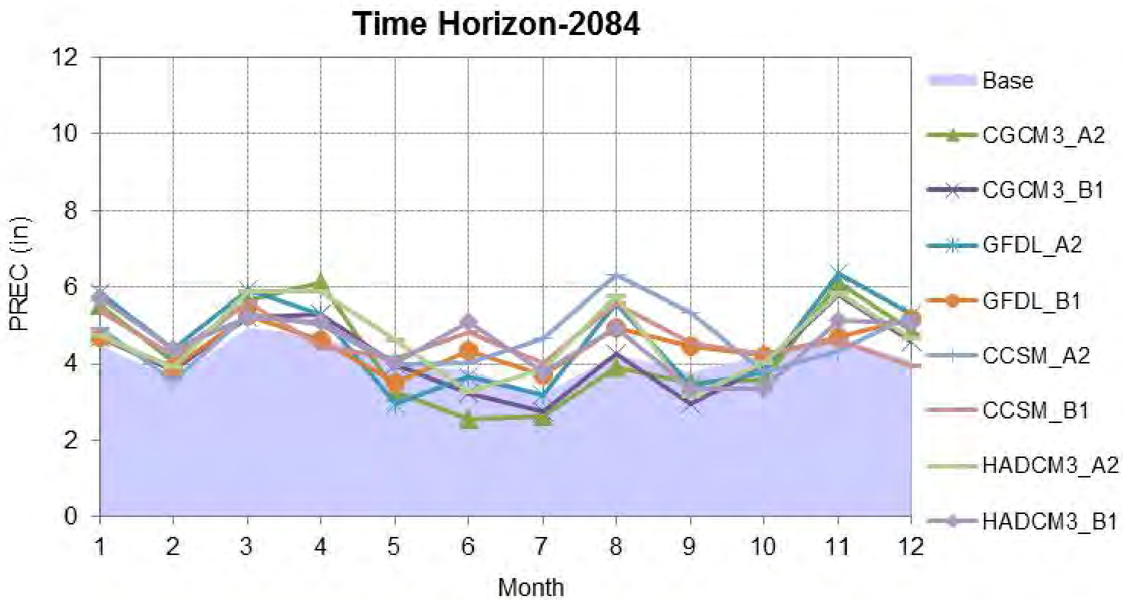


Figure 12. Monthly variation of modeled precipitation for 2084.

Figure 13. Monthly variation of modeled temperature for 2022.

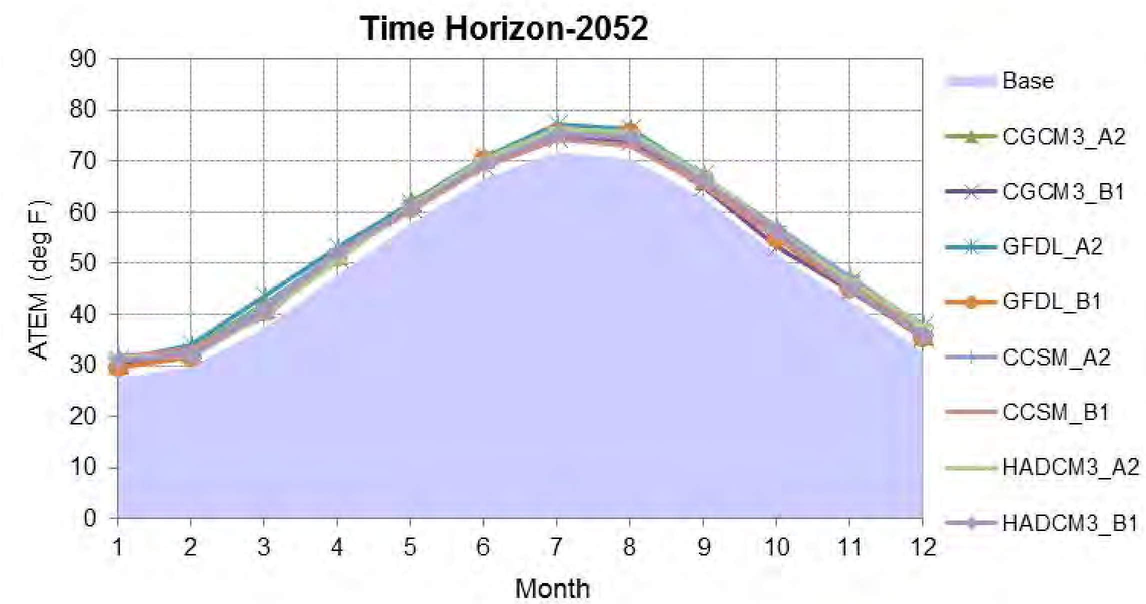


Figure 14. Monthly variation of modeled temperature for 2052.

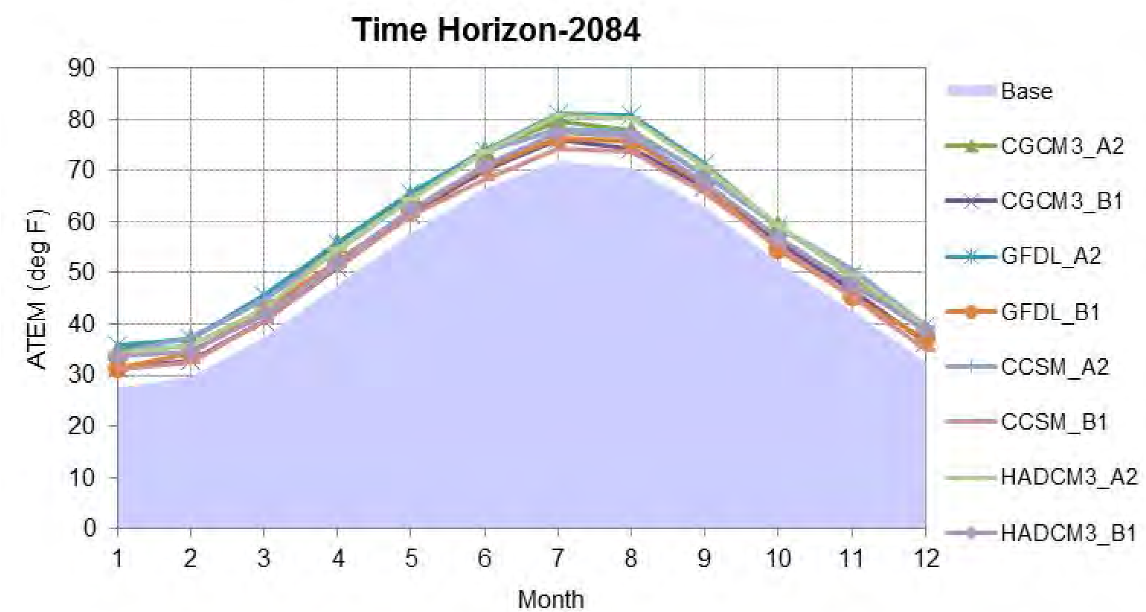


Figure 15. Monthly variation of modeled temperature for 2084.

2.2.2 Hydrologic Changes

Climate change could introduce significant changes in the hydrologic cycle. The frequency of both droughts and flood events could be increased; however, simulation modeling experiments are needed to test these hypotheses. The mobilization and transport of pollutants will also be affected, both as a direct result of hydrologic changes and through changes in plant growth.

At the larger scale, flow volumes and the seasonal timing of flow are of immediate and obvious concern. For this study, hydrologic changes are analyzed for the period from 2008 to 2099. Flows are analyzed in a variety of ways over each 31-year analysis period, including the minimum, median, mean, and maximum change relative to existing conditions among the different scenarios (refer to Table 2). In addition to basic flow statistics, comparisons are made for 100-year flood peak (fit with Log Pearson type III distribution; USGS 1982), average annual 7-day low flow, and Richards-Baker flashiness index (a measure of the frequency and rapidity of short term changes in streamflow; Baker et al. 2004).

Table 2. Range of predicted changes in hydrologic response at the Pawtuxet River Outlet for eight climate scenarios

Time Horizon		2022	2052	2084
Average Annual Flow Volume	Minimum	+4.95%	+4.48%	-8.40%
	Median	+7.32%	+10.31%	+5.14%
	Maximum	+11.93%	+19.63%	+7.27%
7-day Average Low Flow	Minimum	-3.29%	-10.17%	-23.92%
	Median	+5.54%	+7.00%	+1.67%
	Maximum	+16.88%	+35.28%	+32.99%
Richards-Baker Flashiness	Minimum	-2.37%	+1.59%	+1.99%
	Median	+1.70%	+4.22%	+6.13%
	Maximum	+3.99%	+9.30%	+8.82%
100-year Peak Flow	Minimum	-9.19%	-8.74%	-10.45%
	Median	+1.93%	+4.76%	-0.46%
	Maximum	+15.91%	+12.23%	+6.18%

The results of applying the eight climate scenarios over each of the three time horizons are summarized below in several ways. The hydrological response to the climate change scenarios as predicted by the SWAT model over the three time horizons are shown in Figures 16 through 23. The results presented are at the outlet of the Pawtuxet River watershed model.

The first set, Figures 16 through 18, shows the total average flow by month (expressed as cubic meters per second or cms). Separate plots are presented for 2022, 2052, and 2084 meteorological conditions, based on simulation over 31 years of modified historical precipitation. Within each plot, the average response to existing climate ("Baseline") is shown as a blue area in the background. Each of the climate scenario products is shown as a line. For example, CRCM3_A2 is the result of applying the SWAT model to climate predictions generated from the CRCM3 global circulation model (after statistical downscaling) under the A2 emissions storyline. Comparison of these plots show seasonal changes, with fall-winter runoff increasing through 2052 and a spread of different potential futures for summer flows. The seasonal change in flow volume is more pronounced for some climate scenarios than the others.

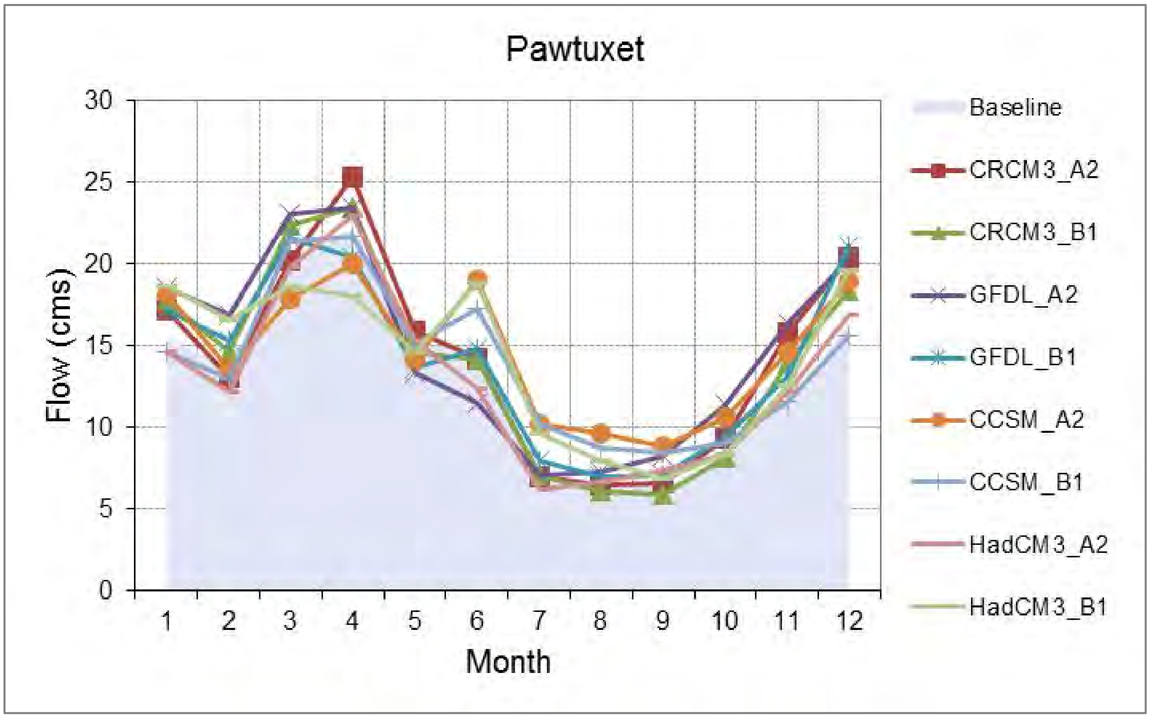


Figure 16. Pawtuxet River SWAT model average monthly flow for time horizon 2022.

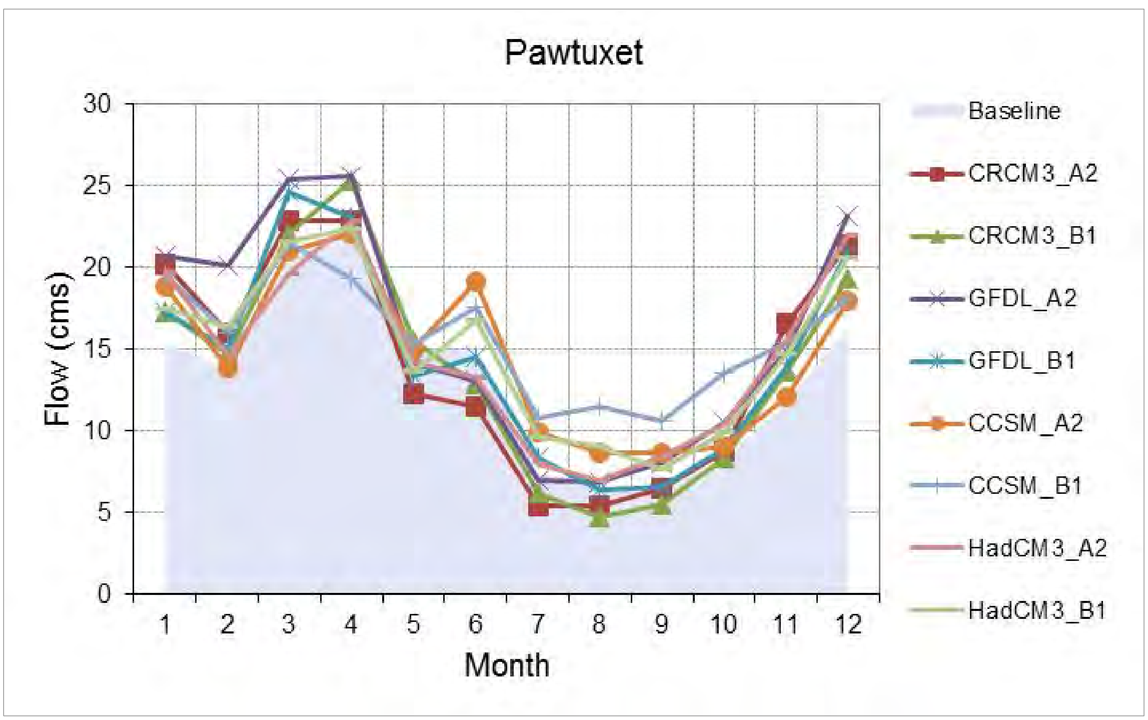


Figure 17. Pawtuxet River SWAT model average monthly flow for time horizon 2052.

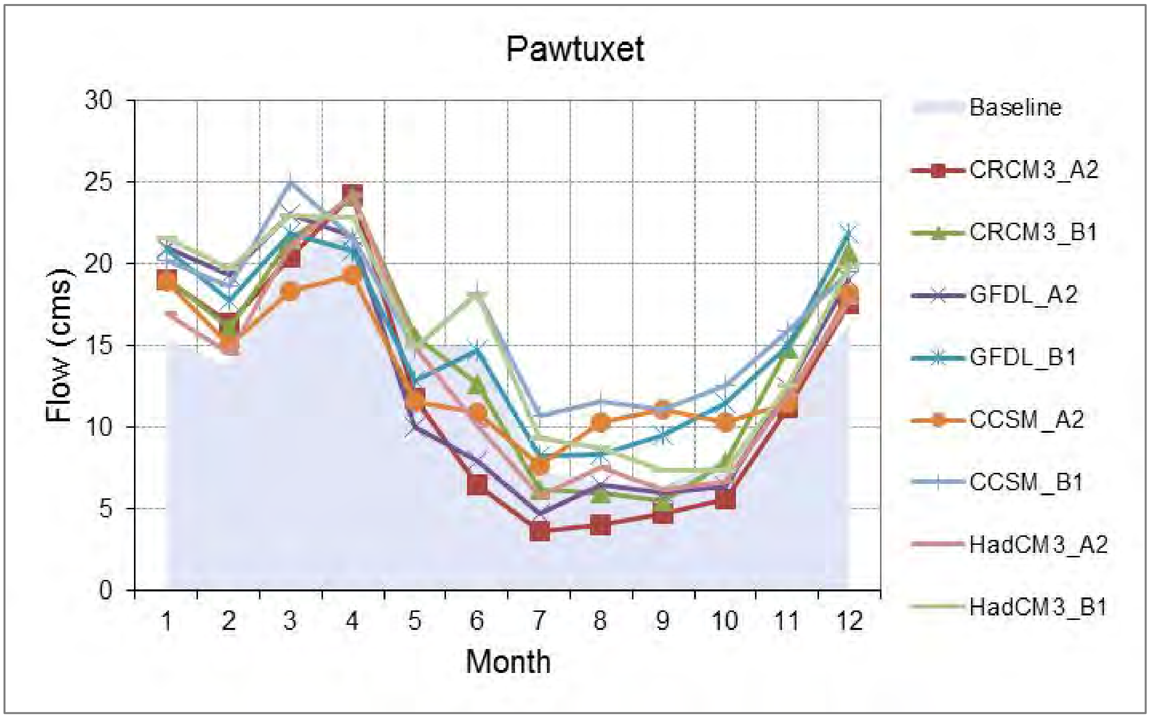


Figure 18. Pawtuxet River SWAT model average monthly flow for time horizon 2084.

Figures 19 through 21 express the scenario results on an annual basis in a different way. These figures show flow-duration curves, which show the cumulative frequency of exceeding a flow of a given magnitude. For example, in Figure 19, the highest flows, which are exceeded less than 1 percent of the time, are slightly greater than 100 cms. In contrast, the lowest flows, which are exceeded nearly 100 percent of the time, are less than 2 cms. The major change noticeable in these plots is an increasing divergence between different climate scenarios over time. For instance, by 2084, the different climate scenarios show a considerable spread above and below the baseline frequency-duration, but do not show much change in the extremes.

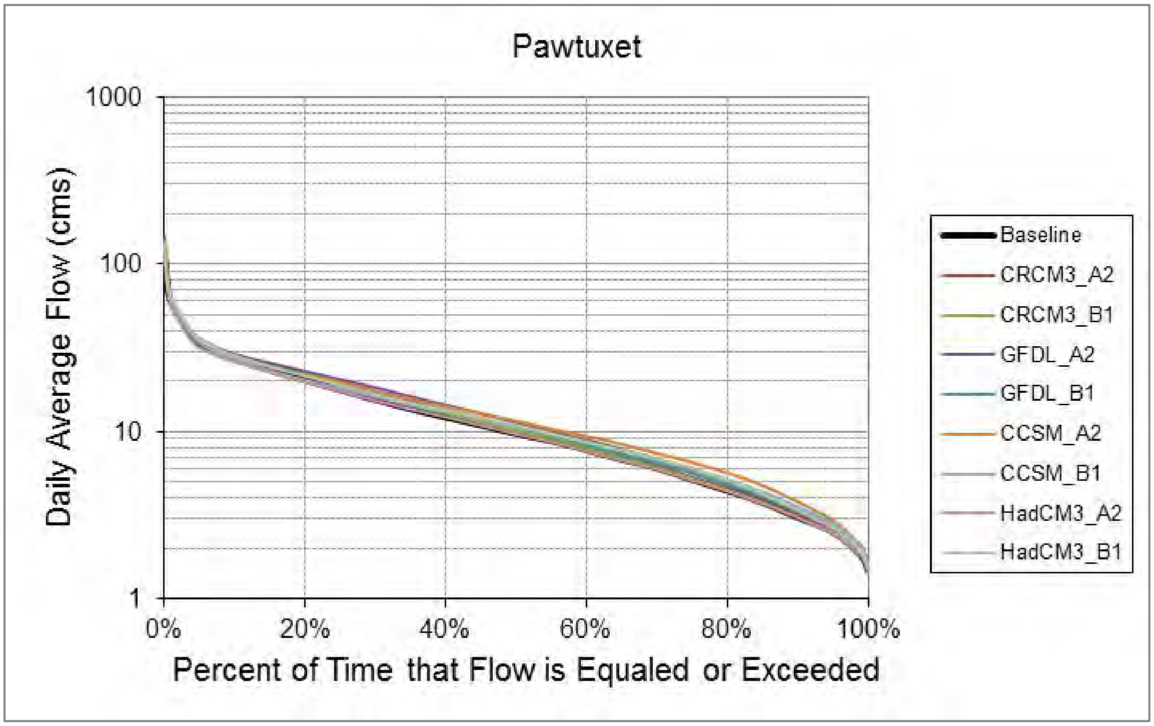


Figure 19. Pawtuxet River SWAT model flow duration curve for time horizon 2022.

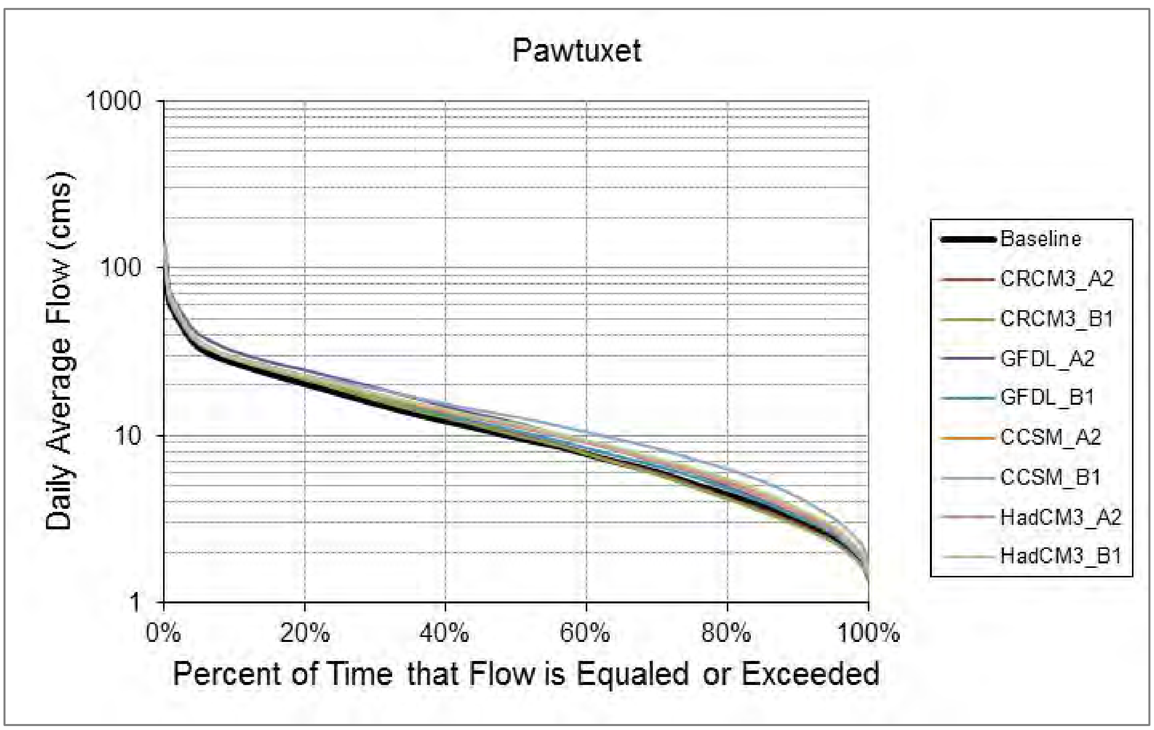


Figure 20. Pawtuxet River SWAT model flow duration curve for time horizon 2052.

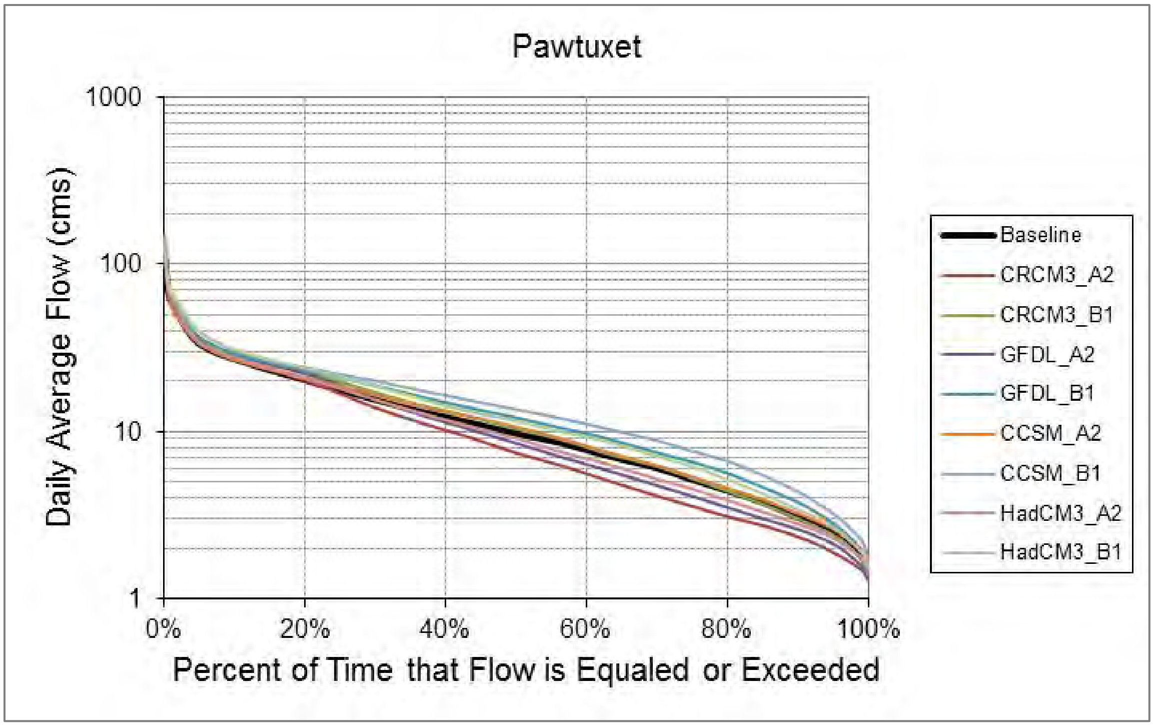


Figure 21. Pawtuxet River SWAT model flow duration curve for time horizon 2084.

Figures 22 through 24 display the total flow volume or water yield from the basin in the form of bar charts (in units of cubic hectometer per year). The majority of cases predict an increase in the total average annual flow volume relative to the current baseline. While the 2022 and 2052 time horizon show a significant increase in flow volumes across all climate scenarios except HadCM3_A2, the 2084 time-horizon shows mixed responses as temperature-related evapotranspiration increases begin to overwhelm the increased total precipitation volume. The 2022 results for HadCM3 point out some of the sensitivities of the system that increase uncertainty in the prediction of water yield. This model predicts a slight decrease in precipitation under the A2 scenario in 2022, coupled with an increase in air temperature and evapotranspiration, leading to decreased flow volume. In contrast, other models predict an increase in precipitation under the A2 scenario in 2022. This apparent anomaly disappears for later time horizons as predicted precipitation from HadCM3_A2 catches up with the other models.

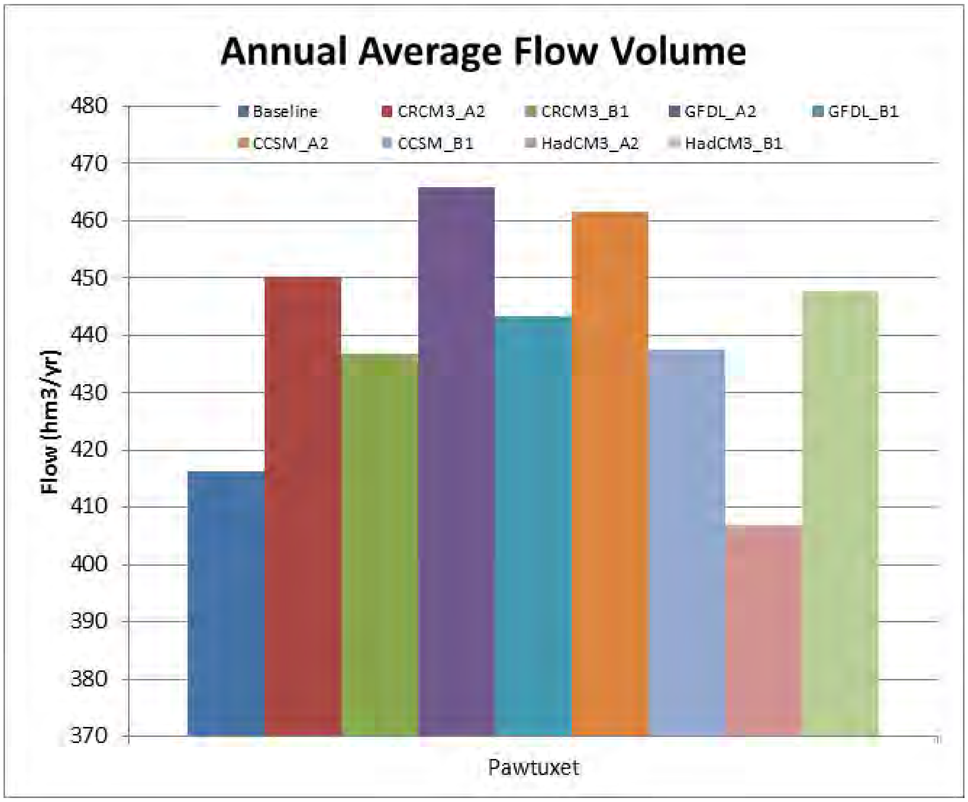


Figure 22. Pawtuxet River SWAT model average annual flow for time horizon 2022.

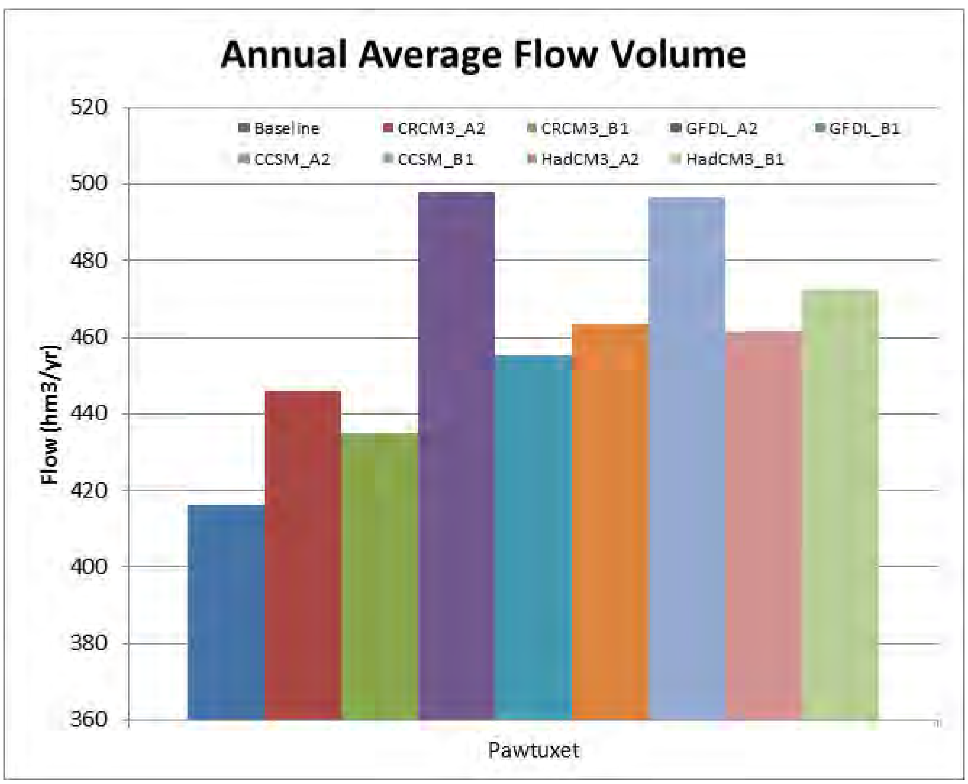


Figure 23. Pawtuxet River SWAT model average annual flow for time horizon 2052.

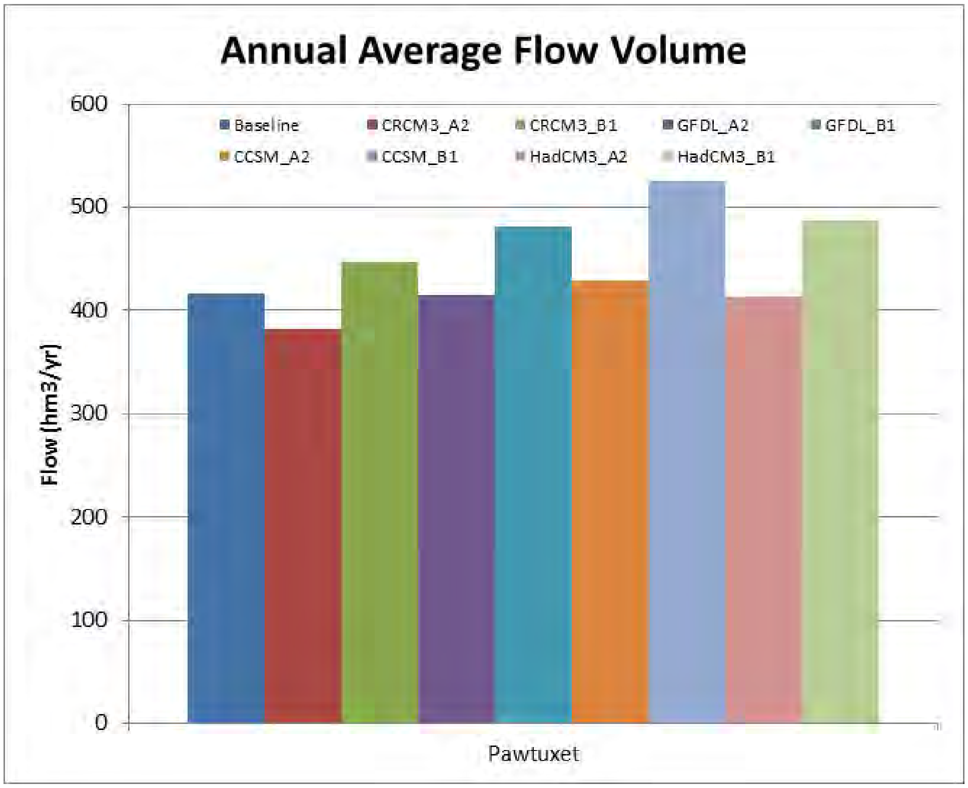


Figure 24. Pawtuxet River SWAT model average annual flow for time horizon 2084.

3.0 DROUGHT ASSESSMENT

Climate change can exacerbate the impacts of a drought because of decreased precipitation and increased evapotranspiration reducing the surface water flows and groundwater availability. These issues can be exacerbated by other stressors such as an increased population and water demand. In this section, the drought hazard assessment (3.1) and the drought impact assessment (3.2) are described.

3.1 Drought Hazard Assessment

According to the U.S. Geological Survey, a drought is a lack or insufficiency of rain for an extended period that severely disturbs the hydrologic cycle in an area.[4] Droughts involve water shortages, crop damage, stream flow reduction, and depletion of groundwater and soil moisture. They occur when evaporation and transpiration exceed precipitation for a considerable period. Rhode Island experiences extended periods of dry weather, typically during the summer months despite getting more rain annually (39–54 inches) than the average for the United States (29.5 inches) (NWS 2012). The state has 1,498 miles of rivers, 20,917 acres of lakes and ponds, 22 major stratified drift aquifers and usable quantities of groundwater in almost all locations from bedrock aquifers.

Drought is the fourth priority hazard in the state's *Hazard Mitigation Plan* (RIEMA 2008). According to the plan, drought has a 5 percent probability of occurring in any given year on the basis of the limited data available. Table 3 shows some of the major historical droughts that have affected the state. For each drought, the National Weather Service notes that the precipitation during the preceding fall and winter months was *below normal* to *much below normal* (90 and 75 percent less than typical levels) before the spring. The 1965-67 drought lasted for three summers. Although short-term droughts, such as the one

[4] As defined online at http://ks.water.usgs.gov/waterwatch/drought/definition.html.

experienced in 1999, might not pose a significant threat for the state's public water systems, no water system is immune to periods of long-term drought (RIEMA 2008).

Table 3. Historical drought

Date	Area Impacted	Impacts
1930-31	State	Stream flow 70% of normal
1941-45	State (Very severe in Pawtuxet and Blackstone Rivers)	Stream flow 70% of normal
1949-50	State	Stream flow 70% of normal
1963-67	State	Water restriction, well replacements common
1980-81	State (Very severe in eastern part of State)	Serious crop damage
1987-88	Southern part of State	Crop Damage ($25M)

Source: NWS 2008
Note: M = million

3.2 Drought Impact Assessment

According to the Rhode Island Water Resources Board, 31 major municipal and private water suppliers provide water to 90 percent of the state population. Rhode Island does not have a regulatory procedure for allocating water statewide or regionally. Water allocation is based on riparian rights, traditional usage, and ad hoc permit approvals. Each water supplier imposes use restrictions when necessary according to the limitations of its system. Historically, this approach to water management has worked because water supply has always exceeded demand.

Generally, the southern part of the state has relied on groundwater aquifers for water supply; the rest of the state relies on surface water reservoirs. Twenty-six percent of Rhode Island's population depends on groundwater for domestic water use. According to HEALTH, Division of Drinking Water Quality, 647 public wells are in the state.

To understand the impact of a future drought, the water supply and demand were assessed. The water supply was assessed at three different time horizons: 2022, 2052, and 2084 for two emission scenarios and four GCMs. The precipitation and flow results presented in Section 2.0 show that, in some cases, values are higher than the baseline and in other cases, they are lower. The GCM and emission scenario which resulted in the lowest flow for each time horizon was identified and that flow was mapped. These low flow scenario maps are presented in Figures 25-27. As the figures show, the 2022 and 2084 time horizons show a decrease in flow for certain reaches, and the 2052 map shows an increase in flow for all reaches. The emissions scenarios, which show the highest negative change in flow were used to generate Figures 25–27 in this section. Figures showing flows for all 24 modeled scenarios are in Section 2 (Figures 16–24).

Each water utility (franchise area) receives its water from the ground, the surface, or a combination of the two. Figure 28 shows each utility and the water source(s). Areas shown in white are not serviced by a water utility.

Historical data show that a major drought lasting 3 years can reduce the drought flow to 70 percent of normal flow. Figures 16–18 in Section 2 show that the flows are seasonally variable with the summer months producing less flow and under some climate change scenarios, an even smaller flow is projected. With climate change reducing some surface water flows by an additional 18 percent as shown in Section 2.2.2, the droughts will be more intense, burdening the water utilities.

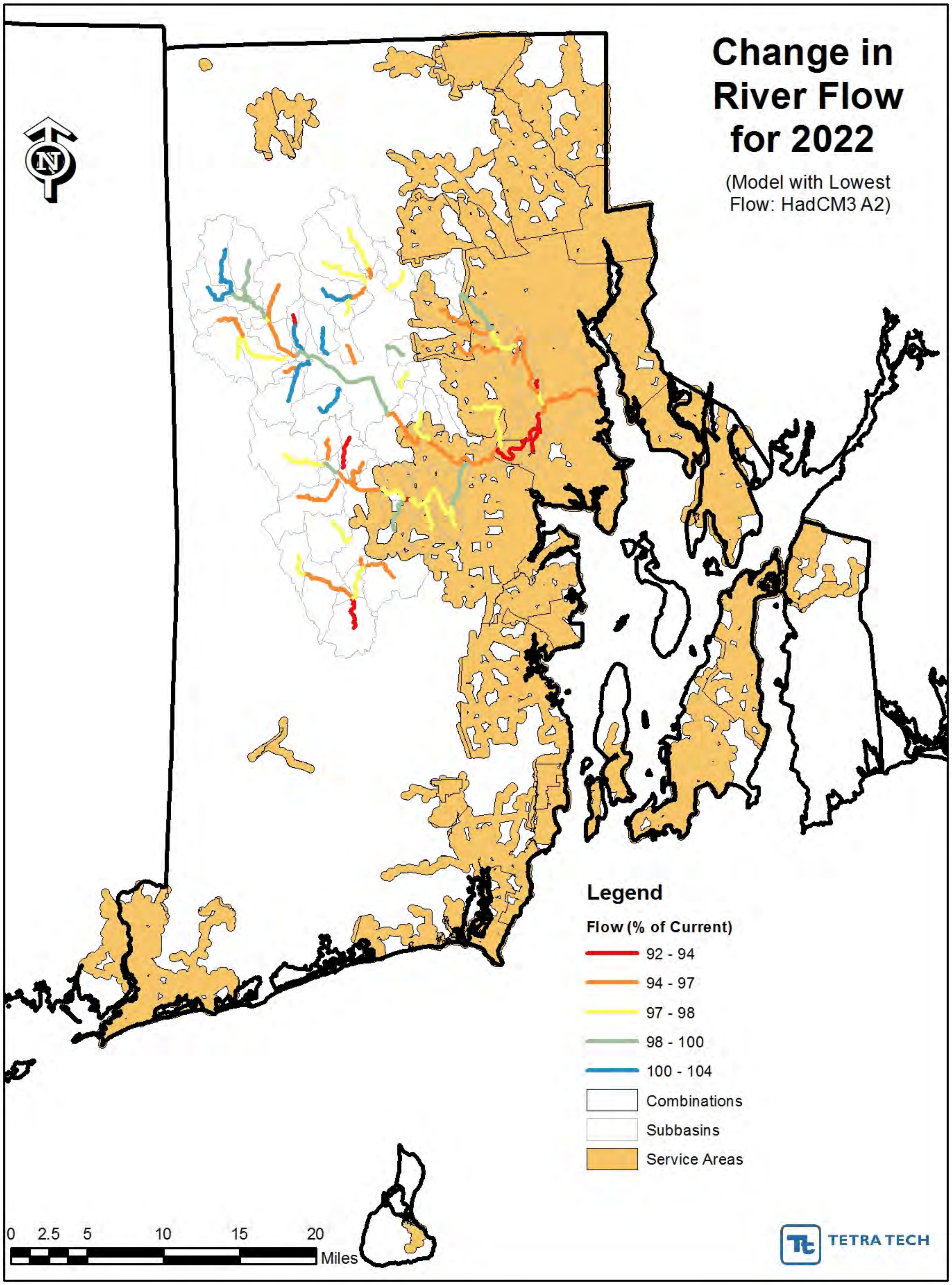


Figure 25. Change in river flow for 2022 (model with lowest flow: HadCM3 A2).

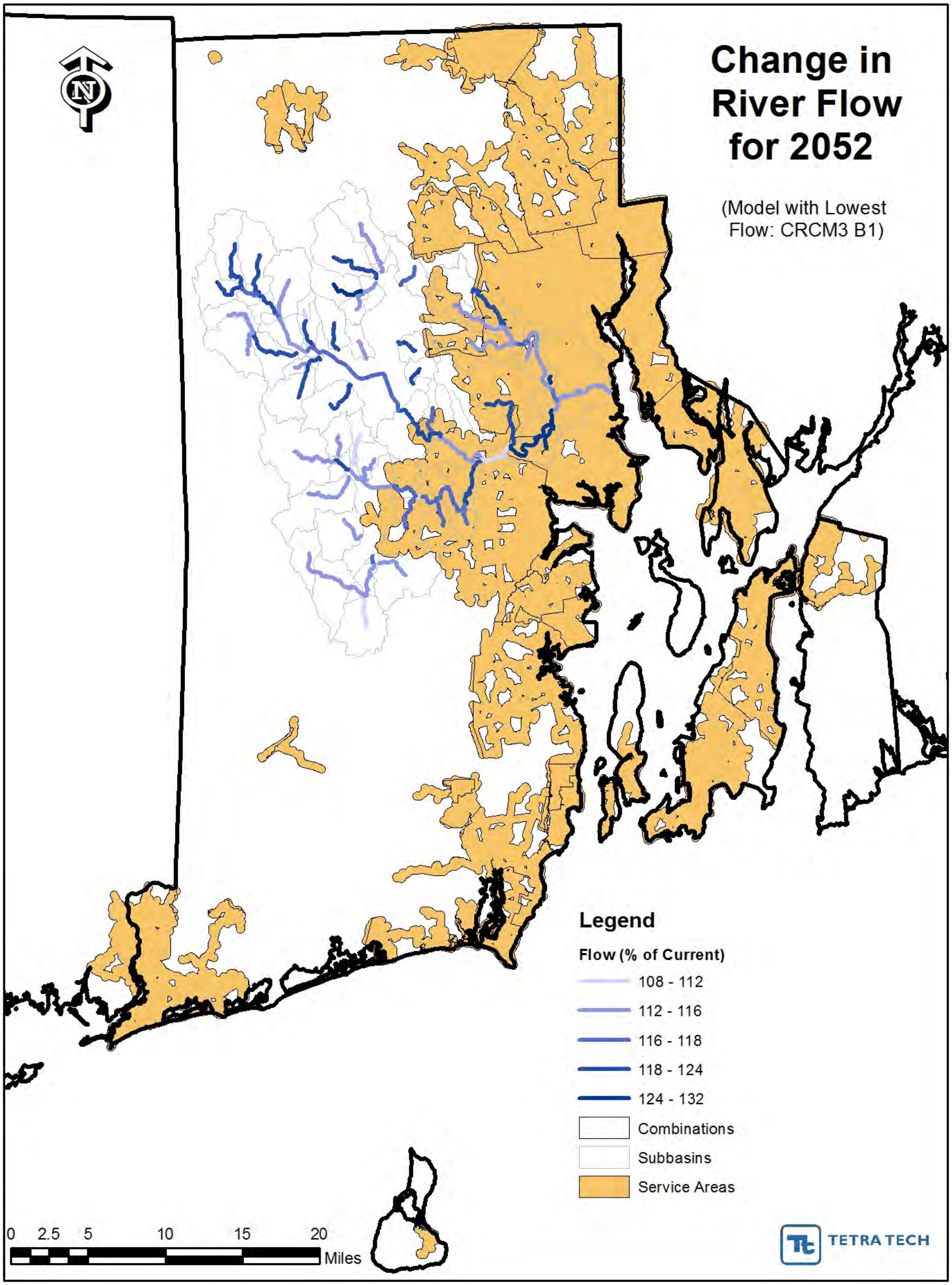


Figure 26. Change in river flow for 2052 (model with lowest flow: CRCM3 B1).

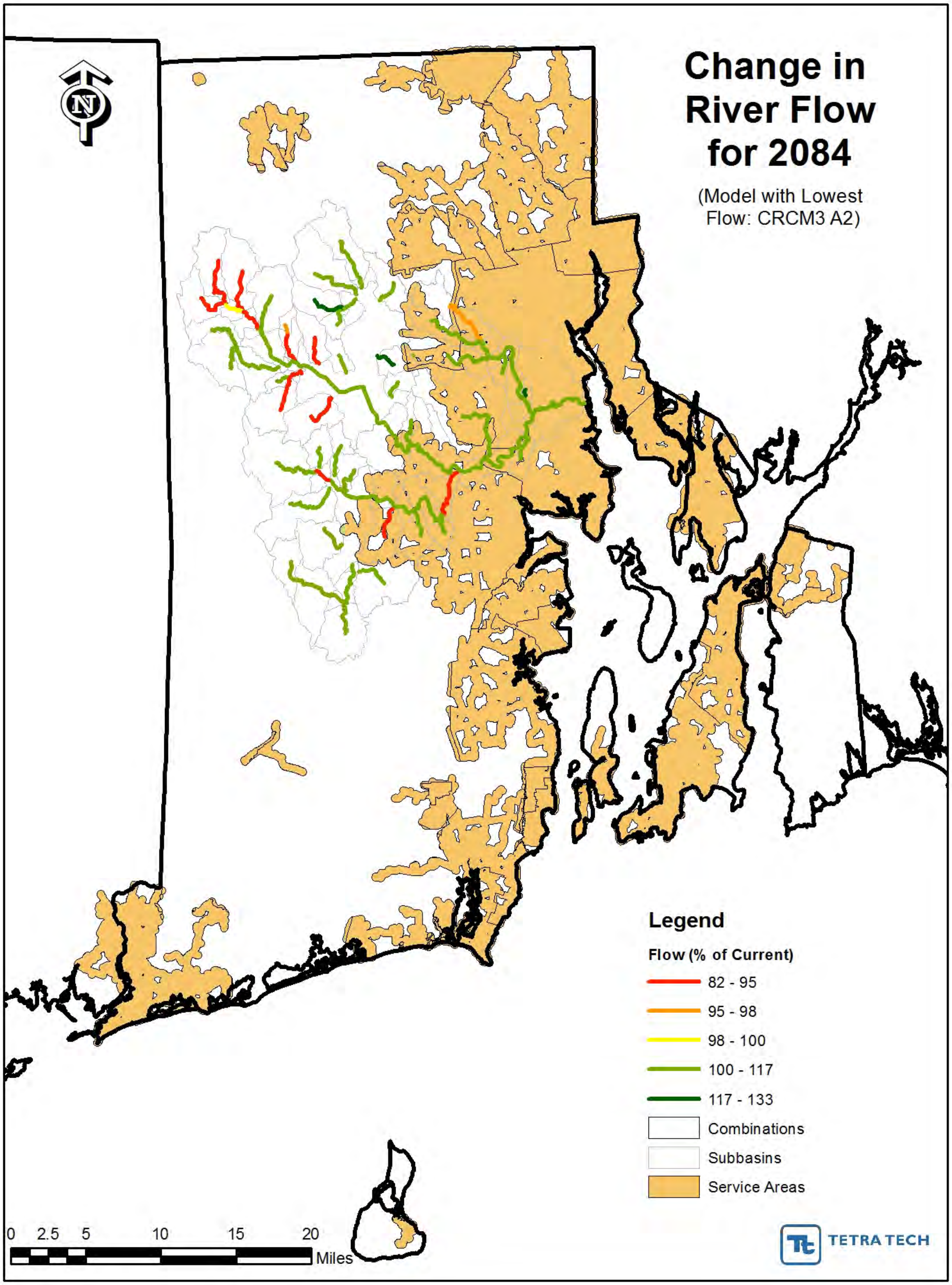


Figure 27. Change in river flow for 2084 (model with lowest flow: CRCM3 A2).

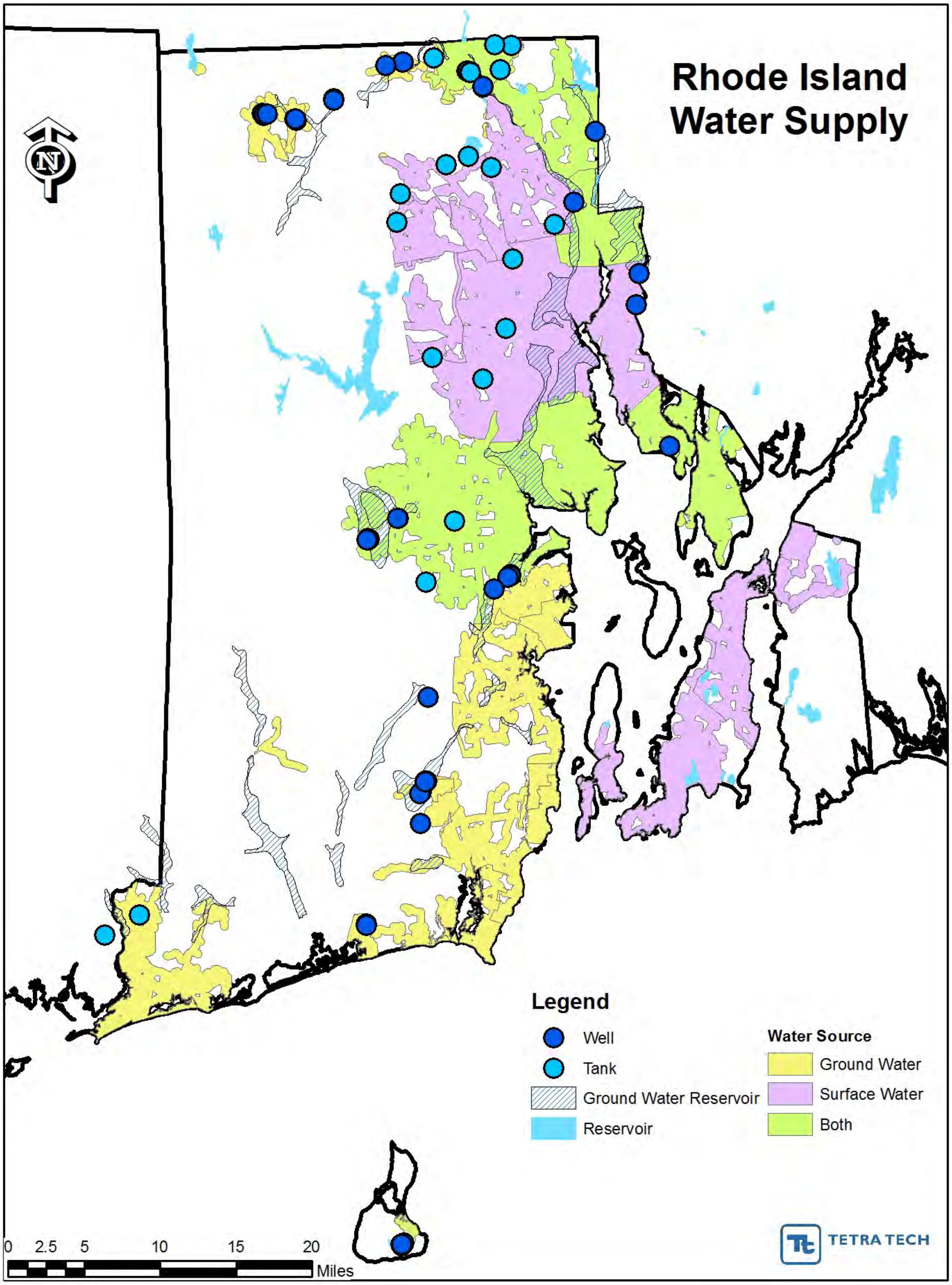
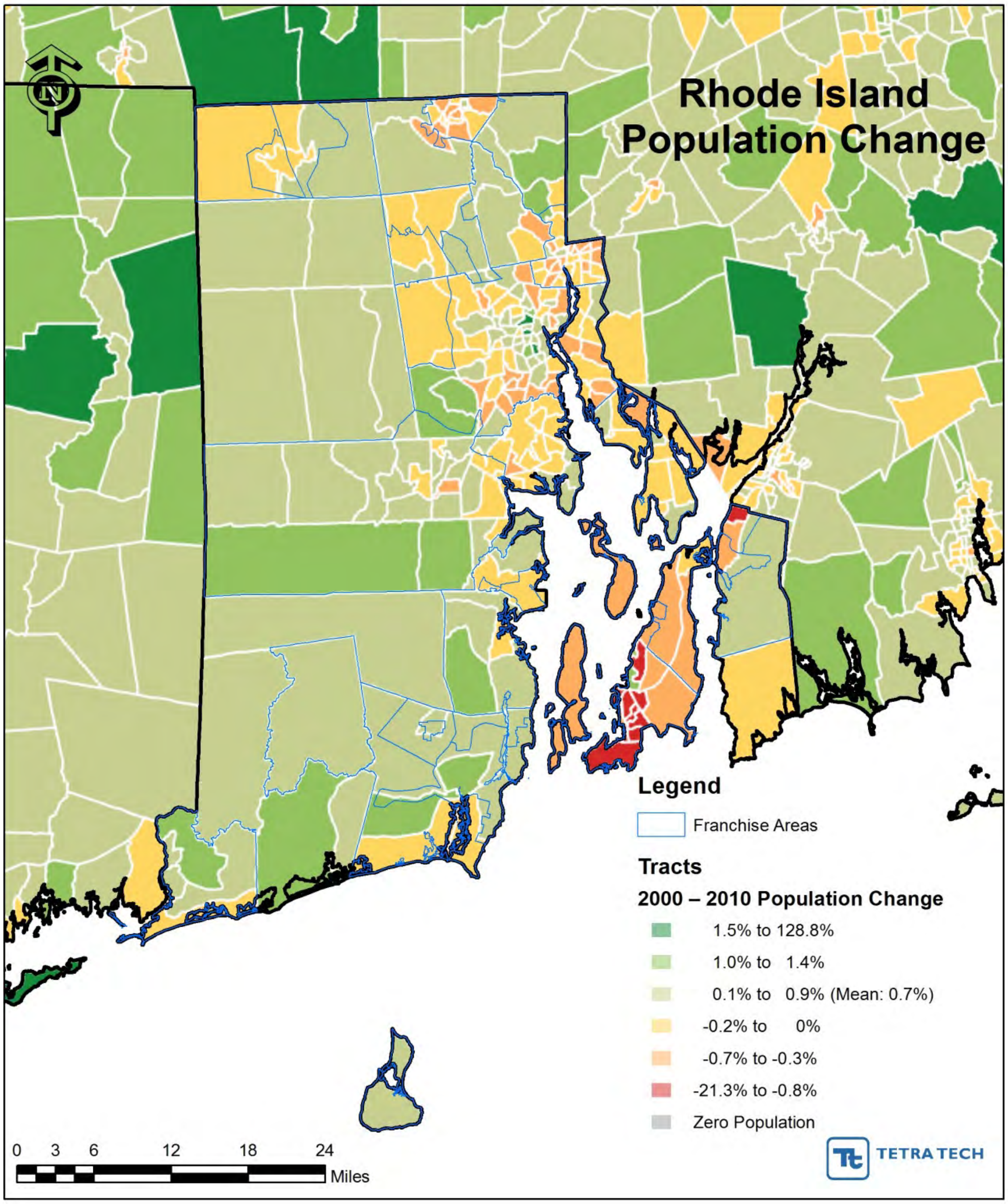


Figure 28. Rhode Island water supply sources.

To understand future water demand, the projected population change was modeled (see Figure 29) and compared with the water utility boundaries. These projections indicate that population increases will increase demand (assuming current use rates) by an average of +0.8 percent (2022), +3.0 percent (2052), and +5.3 percent (2084). To date, the water utilities in Rhode Island have been able to compensate for drought periods by using interconnections to share the water supply and by imposing water restrictions, but with additional demand and a reduced flow, there could be significant economic and social impacts.

The increase in household water demand (e.g., for landscape irrigation) and industrial water demand due to climate change is likely to be rather small, i.e., less than 5 percent by the 2050s at selected locations (Mote et al. 1999; Downing et al. 2003). An indirect but small secondary effect on water demand would be the increased electricity demand for cooling buildings, which would tend to increase water withdrawals for cooling thermal power plants. A statistical analysis of water use in New York City showed that above 25 °C, daily per capita water use increases by 11 liters/1 °C (roughly 2 percent of current daily per capita use) (Protopapas et al. 2000).



Note: The population and demand analysis assumes that water use increase with demand (that is, current use rates continue).

Figure 29. Rhode Island population change.

4.0 SEA-LEVEL RISE ASSESSMENT

The sea level along the coast of Rhode Island has been rising rapidly when compared to the world as a whole. This can be seen by the tide measurements collected by the two National Oceanic and Atmospheric Administration (NOAA) gauging stations shown in Figures 30 and 31. Although other stations are in the state, these two were selected because of the length of time they have been in service. The Newport Station has been collecting data since 1930. It shows an average annual change of +2.58 mm per year (for the period 1930 to present). However, reviewing recent trends (2006 to present), an annual change of +2.70 mm per year is observed (shown in Figure 32). The Providence Station has been collecting data since 1938. It shows an average annual change of +1.95 mm per year (2006 to present). Reviewing the recent trends at this station, an annual change of +2.19 mm per year is observed (2006 to present) (shown in Figure 33).

Using the observed sea-level rise data from NOAA, an EPA sea level rise methodology, and a literature review, two estimates of sea-level rise were developed for each of the three time horizons: 2022, 2052, and 2084. By selecting a low and a high value for each time horizon, a range of depths could be modeled and analyzed. To identify the impacts of sea-level rise, two steps were taken: (1) hazard assessment, and (2) potential impact assessment.

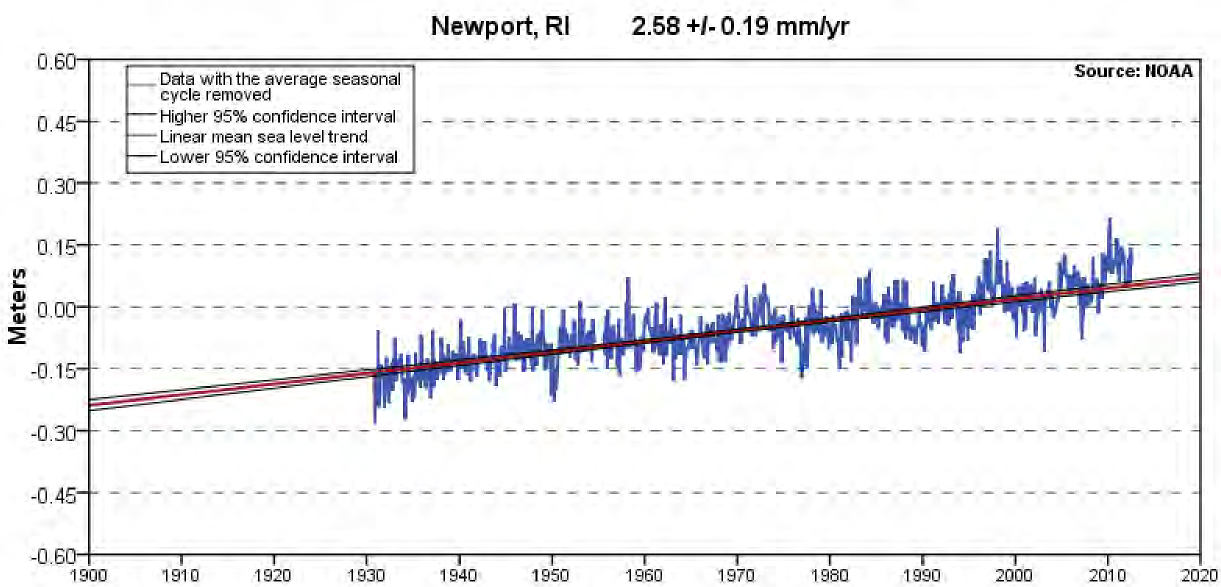


Figure 30. Observed sea level rise - Newport, Rhode Island NOAA gauging station.

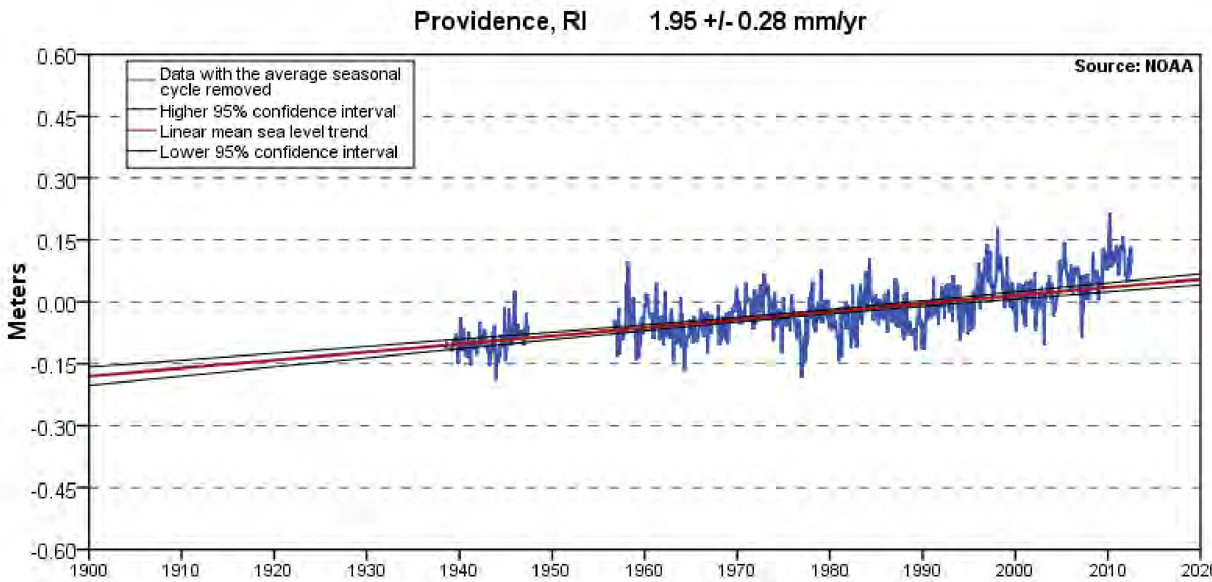


Figure 31. Observed sea level rise - Providence, Rhode Island NOAA gauging station.

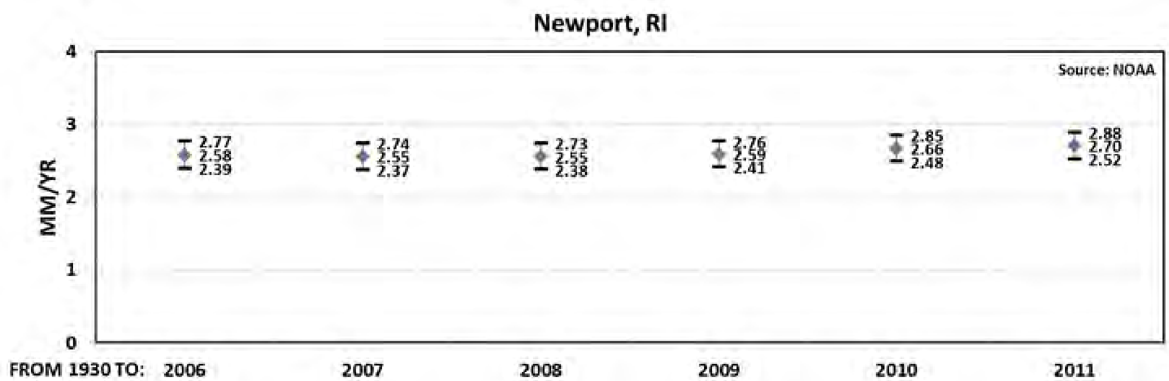


Figure 32. Recent sea level trends - Newport, Rhode Island NOAA gauging station.

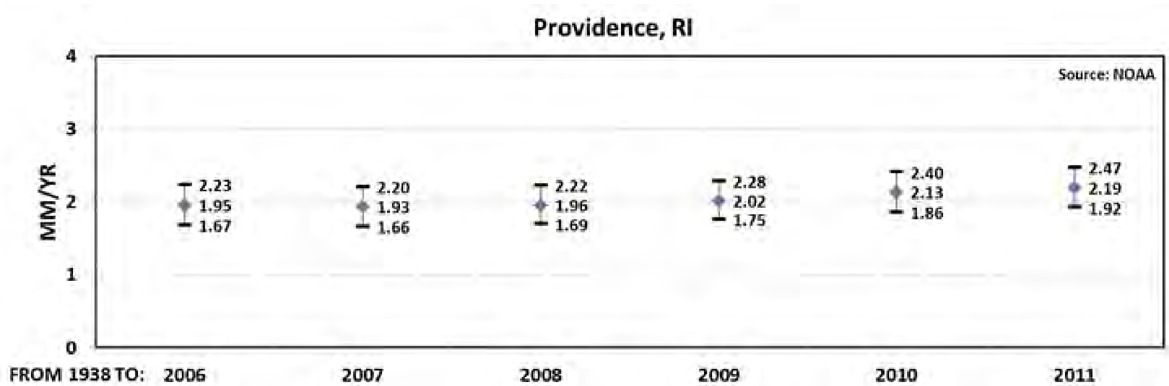


Figure 33. Recent sea level trends - Providence, Rhode Island NOAA gauging station.

4.1 Sea-Level Rise Hazard Assessment

It is important to understand how the sea levels will increase to integrate that information into coastal flooding and storm surge estimates. Infrastructure projected to be underwater because of sea-level rise for the three time horizons is considered a total loss for the purposes of this study; this is because the systems cannot be altered (raised) and would no longer usable. Infrastructure reclamation estimates were not conducted for this project. This section describes how the sea-level rise estimates were developed and the results of the analysis.

The sea-level rise estimation methodology used for this study is based on NOAA's *Incorporating Sea Level Change Scenarios at the Local Level* (NOAA 2012a) and EPA's *The Probability of Sea Level Rise* (USEPA 1995). An estimate was developed for the two selected gauge stations, and the state was divided into two sections by proximity to the stations. Bristol and Newport counties were assigned the Newport Gauge estimates, and Providence, Kent, and Washington counties were assigned the Providence Gauge estimates.

Adding historic trends to published sea-level rise projections double counts whatever portion of the historic local trend was caused by climate change. This double counting can be removed by developing a set of normalized projects in which the historic component of climate change has been removed. The normalized projections estimate the extent to which future sea-level rise will exceed what would have happened if current trends continued. Estimating a local sea-level rise projection can be done using this equation:

$$\text{Local}(t) = \text{normalized}(t) + (t - 1990) \times \text{trend}$$

Table 4 shows the local sea-level rise projections for Newport, and Table 5 shows the projections for Providence. Note that the probability estimates are not based on statistics but on the experts polled for the EPA study. Shaded cells in the table indicate the values used for the sea-level rise estimates. For the 2022 time horizon in Newport, 0.26 and 0.65 feet were used; for the 2052 time horizon, 0.76 and 1.54 feet were used; and for the 2084 time horizon, 1.43 and 2.92 feet were used. For the 2022 time horizon in Providence, 0.25 and 0.63 feet were used; for the 2052 time horizon, 0.70 and 1.48 feet were used; and for the 2084 time horizon, 1.31 and 2.80 feet were used.

Table 4. Newport, Rhode Island sea-level rise increase for three time horizons

Cumulative probability	Sea-level increase (feet)						
	2022	2025	2050	2052	2075	2084	2100
1	-0.22	-0.21	-0.19	-0.19	-0.13	-0.09	-0.01
5	-0.01	0.02	0.21	0.22	0.39	0.46	0.58
10	0.06	0.08	0.30	0.32	0.56	0.65	0.81
20	0.11	0.15	0.43	0.46	0.75	0.88	1.11
30	0.18	0.21	0.53	0.56	0.89	1.04	1.30
40	0.20	0.25	0.60	0.63	1.02	1.17	1.44
50	0.23	0.28	0.66	0.70	1.12	1.29	1.60
60	0.26	0.31	0.76	0.80	1.25	1.43	1.76
70	0.32	0.38	0.83	0.86	1.35	1.57	1.96
80	0.35	0.41	0.93	0.97	1.51	1.77	2.22
90	0.44	0.51	1.09	1.14	1.77	2.06	2.58
95	0.50	0.57	1.22	1.27	1.97	2.32	2.94
97.5	0.59	0.67	1.35	1.41	2.20	2.61	3.34
99	0.65	0.74	1.48	1.54	2.43	2.92	3.80
Mean	0.26	0.31	0.73	0.76	1.22	1.43	1.82

Table 5. Providence, Rhode Island sea-level rise increase for three time horizons

Cumulative probability	Sea-Level Increase (feet)						
	2022	2025	2050	2052	2075	2084	2100
1	-0.23	-0.23	-0.25	-0.25	-0.24	-0.21	-0.16
5	-0.02	-0.01	0.14	0.15	0.29	0.34	0.44
10	0.04	0.06	0.24	0.25	0.45	0.53	0.66
20	0.10	0.13	0.37	0.39	0.65	0.76	0.96
30	0.16	0.19	0.47	0.49	0.78	0.92	1.16
40	0.19	0.22	0.54	0.56	0.91	1.05	1.29
50	0.22	0.26	0.60	0.63	1.01	1.17	1.45
60	0.24	0.29	0.70	0.73	1.14	1.31	1.62
70	0.31	0.36	0.76	0.80	1.24	1.45	1.81
80	0.33	0.39	0.86	0.90	1.40	1.65	2.08
90	0.42	0.49	1.03	1.07	1.67	1.94	2.44
95	0.48	0.55	1.16	1.21	1.86	2.20	2.80
97.5	0.57	0.65	1.29	1.34	2.09	2.49	3.19
99	0.63	0.72	1.42	1.48	2.32	2.80	3.65
Mean	0.25	0.29	0.67	0.70	1.11	1.31	1.67

This methodology was used to identify a mean value and a 1 percent conservative value for each time horizon for each station. These low and high values were used to identify infrastructure at risk and were integrated into the coastal flood and storm surge models.

The Rhode Island Coastal Resources Management Program (CRMP) has begun to integrate a sea-level rise of between 3 to 5 feet (Rubinoff et al. 2008) in its plans and policies. Five feet is greater than the 2084 high scenario for either Providence (2.80 feet) or Newport (2.92 feet) and was integrated into this study's analysis to represent the most conservative value (worst case) for sea-level rise (a 5-foot rise is analyzed in Section 4.2).[5]

4.2 Sea-Level Rise Impact Assessment

Utility facility data was collected including location, value, and construction type. The values were provided by the Rhode Island Water Resources Board and some of the Water Utilities. The sea-level rise maps were overlaid with the facility and infrastructure data to help determine impacts. It is assumed that all infrastructure underwater would be a total loss. Figure 34 shows sea level rise impacts on Rhode Island water utilities (2022, 2052, 2084 [based on Tables 4 and 5], and 5-foot). The losses from the 5 foot sea level rise estimation are shown in Figure 35.

Tables 6 and 7 identify the infrastructure underwater and assign a loss. Table 8 shows the loss by water utility. Appendix B depicts the sea-level rise estimates around 28 facilities.[6] Appendix C provides detailed maps of the areas impacted by sea-level rise. The losses shown in Appendix C are for infrastructure only and do not address lost revenue due to reduced water service capabilities.

[5] In fact, a recent NOAA report indicates that global sea levels could rise up to 6.6 feet by the end of this century (NOAA 2012b).
[6] The facilities which have been mapped in Appendix B were identified during the assessment as facilities which may be severely impacted by more than one future hazard.

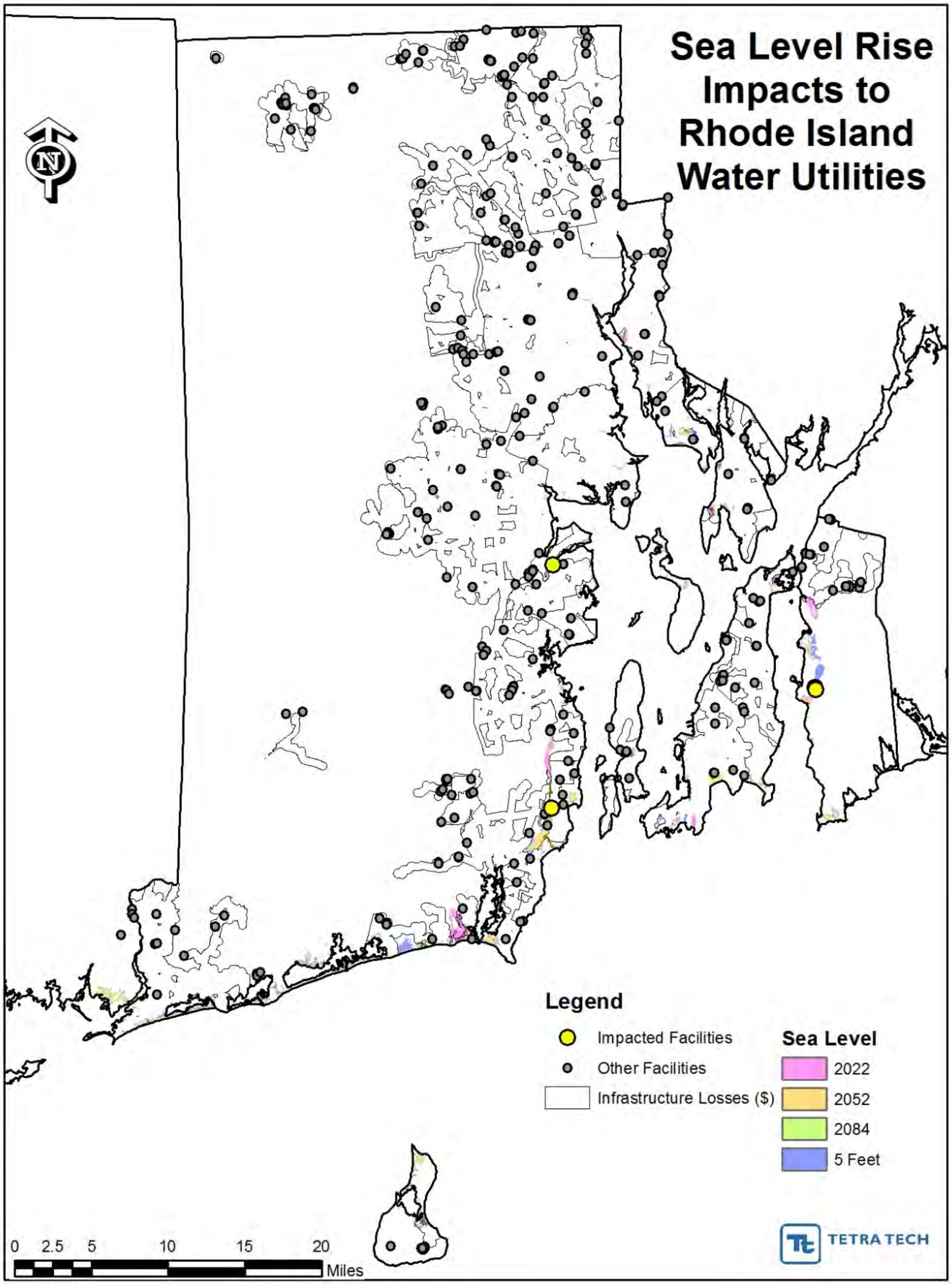


Figure 34. Sea level rise impacts on Rhode Island water utilities.

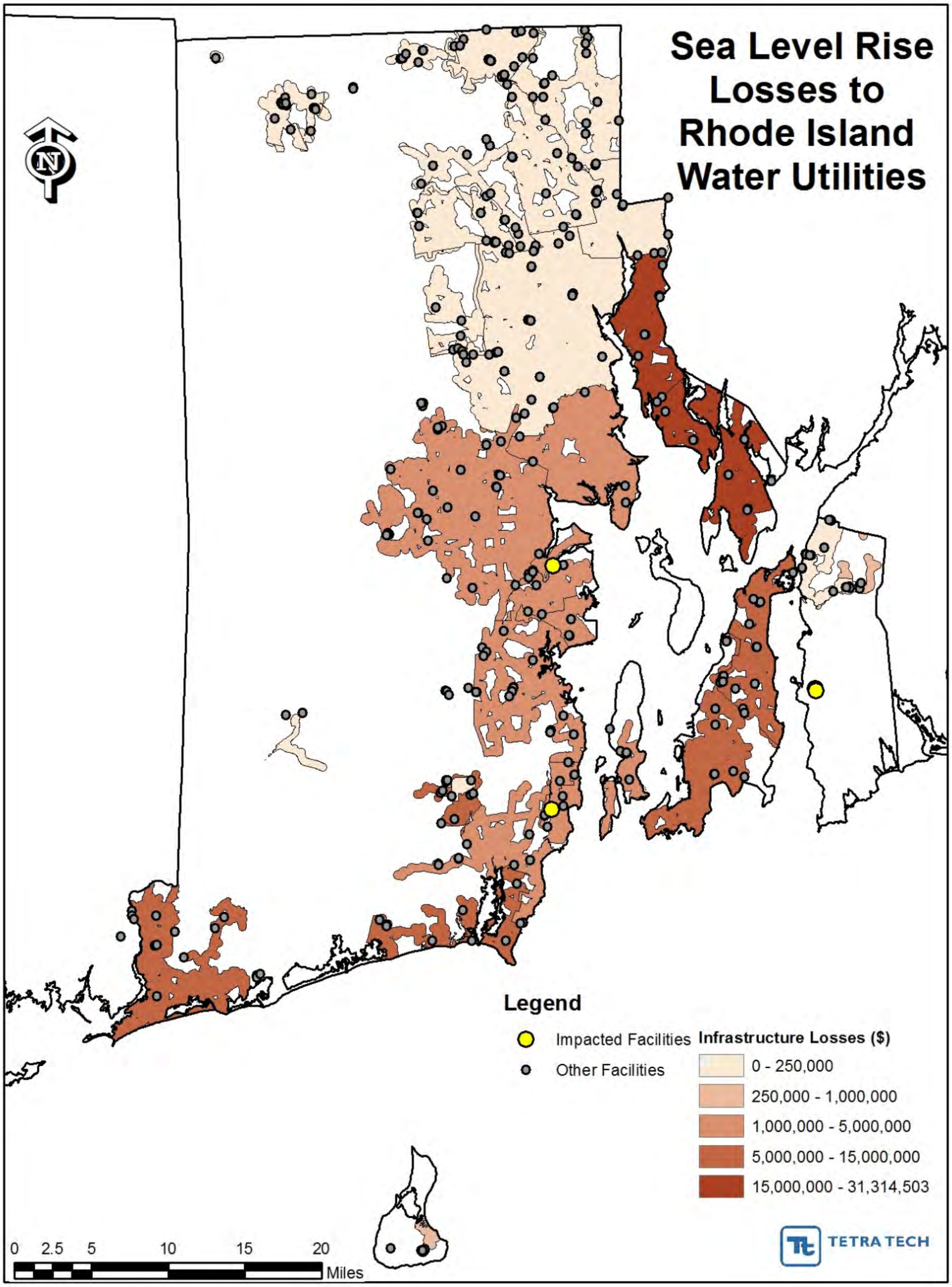


Figure 35. Sea level rise losses to Rhode Island water utilities

Table 6. Pipeline losses due to sea level rise

	Total		2022			2052			2084			5Ft		
WATER UTILITY	Ft.	$	Ft.	%	$	Ft.	%	$	Ft.	%	$	Ft.	%	$
Block Island Water Works	28532	$4,707,861	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	3495	12.3%	$576,725
Bristol County Water Authority	1334160	$220,136,382	113752	8.5%	$18,769,110	130467	9.8%	$21,527,093	149191	11.2%	$24,616,449	189785	14.2%	$31,314,503
Cumberland Water Department	651744	$107,537,760	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
East Providence Public Works	1066007	$175,891,172	3463	0.3%	$571,409	3793	0.4%	$625,909	6186	0.6%	$1,020,632	10394	1.0%	$1,715,034
Greenville Water District	276163	$45,566,936	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Harrisville Fire District	71142	$11,738,391	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Jamestown Water Division	139952	$23,092,139	3014	2.2%	$497,240	3014	2.2%	$497,240	3014	2.2%	$497,240	14829	10.6%	$2,446,780
Johnston Water Control Facility	204995	$33,824,203	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Kent County Water Authority	2219161	$366,161,494	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	6871	0.3%	$1,133,740
Kingstown Water Department	108599	$17,918,884	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Lincoln Water Commission	627271	$103,499,646	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Narragansett Water Dept - North End System	144080	$23,773,169	0	0.0%	$0	0	0.0%	$0	515	0.4%	$84,936	4023	2.8%	$663,788
Narragansett Water Dept - South End System	274706	$45,326,570	0	0.0%	$0	1566	0.6%	$258,406	7729	2.8%	$1,275,364	39761	14.5%	$6,560,647
Newport Water Department	1052940	$173,735,141	4906	0.5%	$809,572	6703	0.6%	$1,106,072	8435	0.8%	$1,391,743	32183	3.1%	$5,310,257
North Kingstown Water Department	924535	$152,548,230	0	0.0%	$0	0	0.0%	$0	2266	0.2%	$373,969	16782	1.8%	$2,769,079
North Smithfield Water Department	49277	$8,130,661	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
North Tiverton Fire District	169115	$27,904,021	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Pascoag Utility District	96346	$15,897,130	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Pawtucket Water Supply Board	1484427	$244,930,449	380	0.0%	$62,764	380	0.0%	$62,764	655	0.0%	$108,102	655	0.0%	$108,102
Portsmouth Water District	577582	$95,301,031	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	15123	2.6%	$2,495,333
Providence Water Supply Board	5616278	$926,685,829	717	0.0%	$118,297	717	0.0%	$118,297	1955	0.0%	$322,623	10825	0.2%	$1,786,121
RI Economic Development District	221121	$36,485,029	1146	0.5%	$189,127	1146	0.5%	$189,127	1146	0.5%	$189,127	1146	0.5%	$189,127
Richmond Water Supply System	31890	$5,261,805	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Smithfield Water Supply Board	191938	$31,669,818	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
South Kingstown Water Department	295	$48,649	0	0.0%	$0	147	50.0%	$24,319	183	62.0%	$30,186	183	62.0%	$30,186
Sth Kingstown Water Dept - Middlebridge	19004	$3,135,689	0	0.0%	$0	1274	6.7%	$210,223	2386	12.6%	$393,614	7172	37.7%	$1,183,414
Sth Kingstown Water Dept - South Shore	237813	$39,239,211	1172	0.5%	$193,326	7287	3.1%	$1,202,331	14758	6.2%	$2,435,107	34025	14.3%	$5,614,176
Stone Bridge Fire District	107842	$17,794,001	1379	1.3%	$227,472	1379	1.3%	$227,472	1379	1.3%	$227,472	3301	3.1%	$544,666
Stone Bridge Water District	17429	$2,875,737	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
United Water Rhode Island	587886	$97,001,256	0	0.0%	$0	2367	0.4%	$390,599	4760	0.8%	$785,418	10552	1.8%	$1,741,040
URI Facilities & Operations	56323	$9,293,298	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Warwick Water Department	1792303	$295,730,003	2885	0.2%	$476,022	2885	0.2%	$476,022	7971	0.4%	$1,315,236	31304	1.7%	$5,165,098
Westerly Water Department	1138782	$187,898,950	2544	0.2%	$419,727	3506	0.3%	$578,481	28207	2.5%	$4,654,093	75419	6.6%	$12,444,159
Woonsocket Public Works	741082	$122,278,455	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
Zamborano Memorial Hospital	9583	$1,581,170	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0	0	0.0%	$0
	22270304	$3,674,600,169	135358	0.6%	$22,334,065	166632	0.7%	$27,494,354	240735.2	1.1%	$39,721,311	507830	2.3%	$83,791,975

Table 7. Facility losses due to sea level rise

ID	Name	Type	Status	Distribution	2022	2052	2084	5 feet SLR
154	Sakonnet River Pump Station	Booster Pump Station	two 8 mgd & one 6 mgd pumps	Newport Water Works	$0	$0	$0	$500,000
200	Middlebridge to South Kingstown	Interconnection	Receiving/Supply/Daily/Good	United Water Rhode Island	$0	$0	$0	$1,000,000
220	SK/Middlebridge - UWRI Connection	Interconnection	Two Way/12inch.-- Supplies Middlebridge	South Kingstown Water Department	$0	$0	$0	$1,000,000
315	United Water/Narragansett Water	Interconnection	n/a	Narragansett Water Department	$0	$0	$0	$1,000,000
415	Old Nonquit Pump Sta	Booster Pump Station		Newport Water Works	$0	$0	$0	$200,000
					$0	$0	$0	**$3,700,000**

Table 8. Economic effects on utilities

WATER UTILITY	2022	2052	2084	5-Foot
Block Island Water Works	$0	$0	$0	$576,725
Bristol County Water Authority	$18,769,110	$21,527,093	$24,616,449	$31,314,503
Cumberland Water Department	$0	$0	$0	$0
East Providence Public Works	$571,409	$625,909	$1,020,632	$1,715,034
Greenville Water District	$0	$0	$0	$0
Harrisville Fire District	$0	$0	$0	$0
Jamestown Water Division	$497,240	$497,240	$497,240	$2,446,780
Johnston Water Control Facility	$0	$0	$0	$0
Kent County Water Authority	$0	$0	$0	$1,133,740
Kingstown Water Department	$0	$0	$0	$0
Lincoln Water Commission	$0	$0	$0	$0
Narragansett Water Dept - North End System	$0	$0	$84,936	$663,788
Narragansett Water Dept - South End System	$0	$258,406	$1,275,364	$7,560,647
Newport Water Department	$809,572	$1,106,072	$1,391,743	$6,010,257
North Kingstown Water Department	$0	$0	$373,969	$2,769,079
North Smithfield Water Department	$0	$0	$0	$0
North Tiverton Fire District	$0	$0	$0	$0
Pascoag Utility District	$0	$0	$0	$0
Pawtucket Water Supply Board	$62,764	$62,764	$108,102	$108,102
Portsmouth Water District	$0	$0	$0	$2,495,333
Providence Water Supply Board	$118,297	$118,297	$322,623	$1,786,121
RI Economic Development District	$189,127	$189,127	$189,127	$189,127
Richmond Water Supply System	$0	$0	$0	$0
Smithfield Water Supply Board	$0	$0	$0	$0
South Kingstown Water Department	$0	$24,319	$30,186	$1,030,186
Sth Kingstown Water Dept - Middlebridge	$0	$210,223	$393,614	$1,183,414
Sth Kingstown Water Dept - South Shore	$193,326	$1,202,331	$2,435,107	$5,614,176
Stone Bridge Fire District	$227,472	$227,472	$227,472	$544,666
Stone Bridge Water District	$0	$0	$0	$0
United Water Rhode Island	$0	$390,599	$785,418	$2,741,040
URI Facilities & Operations	$0	$0	$0	$0
Warwick Water Department	$476,022	$476,022	$1,315,236	$5,165,098
Westerly Water Department	$419,727	$578,481	$4,654,093	$12,444,159
Woonsocket Public Works	$0	$0	$0	$0
Zamborano Memorial Hospital	$0	$0	$0	$0
	$22,334,065	**$27,494,354**	**$39,721,311**	**$87,491,975**

The results show that 36 water utilities would be adversely affected by sea-level rise for all future periods. The Bristol County Water Authority and the Westerly Water Department would incur more than $10 million each in pipeline losses. Newport Water Works, United Water Rhode Island, South Kingstown Water Department, and Narragansett Water Department would lose booster pump stations and interconnections. These losses assume that no adaptation efforts are taken in the intervening years. The total losses are $22.3 million for 2022, $27.5 million for 2052, $39.7 million for 2084, and $87.5 million for the 5-foot estimate.

5.0 COASTAL FLOOD ASSESSMENT

Flooding was ranked as a priority hazard in the *Rhode Island Hazard Mitigation Plan* developed by the Department of Emergency Management (RIEMA 2008). Coastal flooding can be a result of storm surge, nor'easters, wind-driven waves, coastal erosion, and sea-level rise. These events can work alone or together to create coastal flooding in Rhode Island. As the climate changes, sea-level rise, increased precipitation, and increased storminess could affect the extent and depth of the coastal floodplains and the resulting damage to water utilities. To better understand the impacts, the future floodplain needs to be identified.

5.1 Coastal Flood Hazard Assessment

The coastal flood assessment integrated data on sea-level rise (described in Section 4), coastal erosion (collected from the Coastal Resources Management Council), and a Federal Emergency Management Agency (FEMA) Flood Insurance Study (FEMA 2006). Coastal floodplains were developed for 100-year events at three time horizons (2022, 2052, and 2084) for low and high sea-level rise scenarios and for the 5-foot sea-level rise scenario.

The methodology used to delineate the future coastal floodplains involved a three-step process: (1) conduct an erosion assessment; (2) run a simplified Wave Height Analysis for Flood Insurance Studies (WHAFIS) model; and (3) run a Wave Runup Model following the procedures in the *U.S. Army Corps of Engineers Coastal Engineering Manual* (USACE 2003). For the first step, FEMA's HAZUS-MH software was used to complete the last two steps and the digital elevation model was eroded on the basis of historical erosion trends.

The erosion assessment was conducted using erosion measurements, which have been collected since 1939. The data can be seen in Figure 36. The digital elevation model was eroded using the average annual erosion rate and integrated into the HAZUS model. A digital elevation model with a resolution of one-ninth arc second (~3 meters) was used because of its accuracy and the ability for the model to process quickly. Light Detection And Ranging data were not used because of the time constraints of the project.

The coastal floodplain modeling methodology produced a flood depth grid that estimates the extents and depth of flooding. For each time horizon, two flood depth grids were developed providing a low and high estimate of the flooding. These flood depth grids were then overlaid on the water facility data to generate damage and loss estimates. HAZUS-MH provided these loss estimates on the basis of vulnerability functions for water infrastructure; in contrast to sea-level rise where submerged facilities are lost permanently, the vulnerability functions assume a percent of loss associated with a flood event with infrastructure being repaired following the event. So unlike sea level rise where the infrastructure was considered a total loss, this would be the loss associated with the flood. An example of one of these vulnerability functions is shown in Figure 37. The flood loss estimates are discussed under 5.2, Impact Assessment.

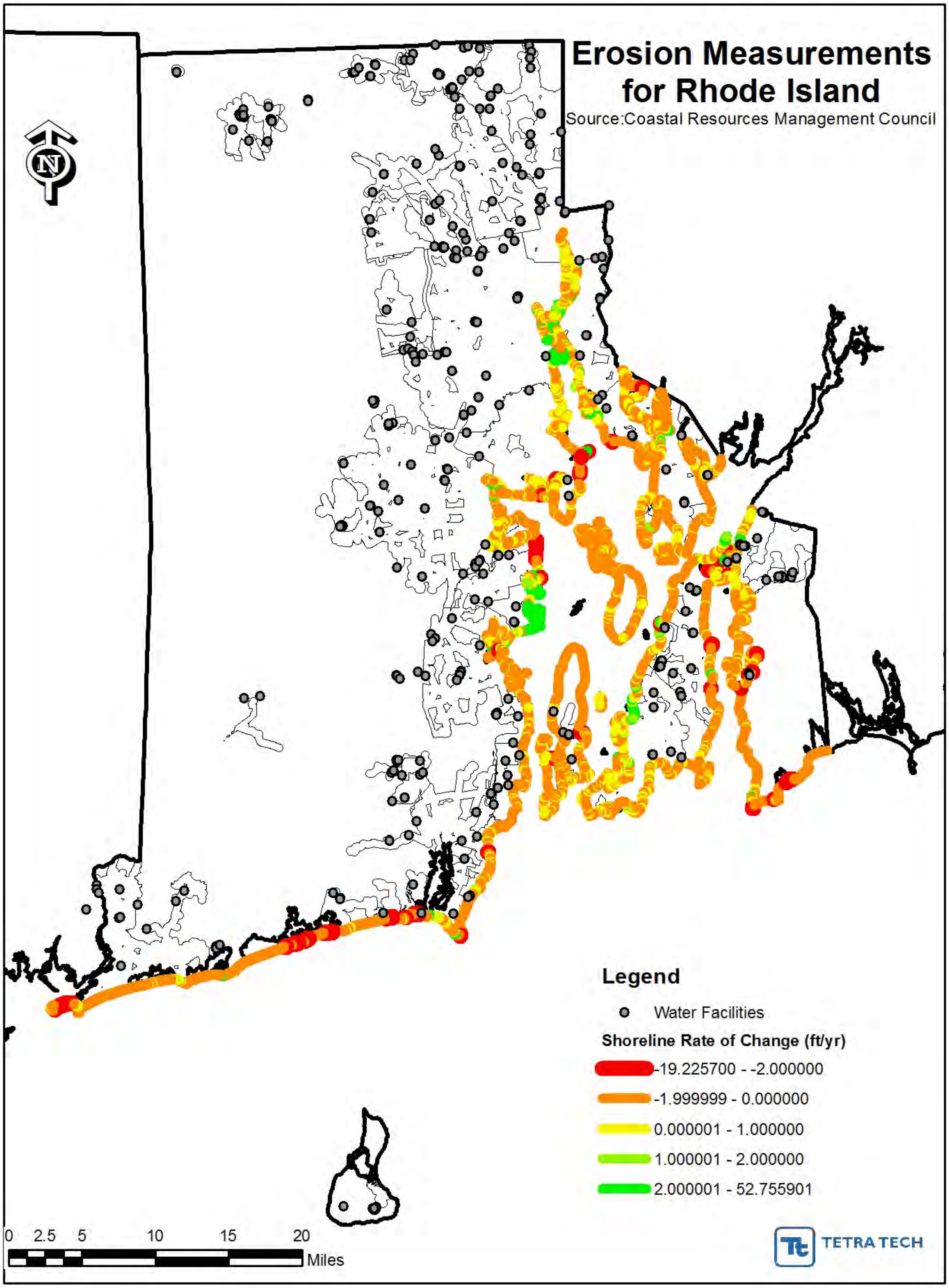


Figure 36. Erosion rates for Rhode Island (1939 to present).

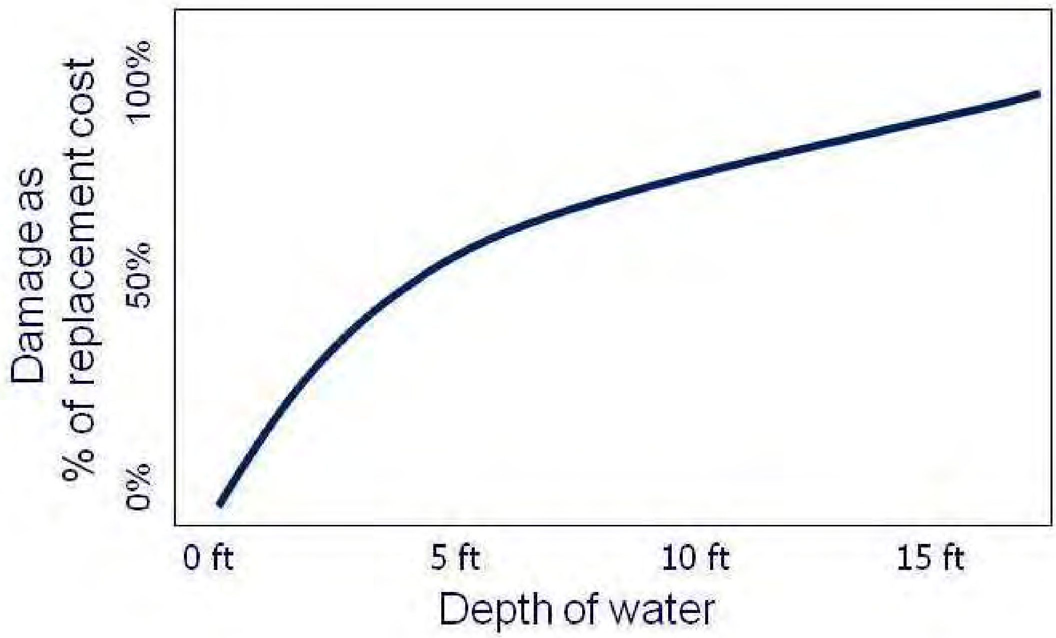


Figure 37. Flood vulnerability function.

5.2 Coastal Flood Impact Assessment

Utility facility data were collected for location, value, and construction type. Losses were calculated for infrastructure in the 100-year coastal floodplain for the three time horizons and the 5-foot prediction. Figure 38 shows Rhode Island, the facilities modeled, and the coastal floodplain. The loss by water utility is shown in Figure 39. Tables 9, 10, 11, and 12 identify the infrastructure affected, the depth of flooding at the site, and loss estimations. For each time horizon, there is a low and high estimation of sea level rise. Appendix B depicts the coastal floodplain around 28 at risk facilities. Table 13 shows the infrastructure losses by utility. Appendix D provides detailed maps of the areas impacted by coastal flooding.

The results show that major infrastructure is at risk, owned by the Bristol County Water Authority, Jamestown Water Division, and Newport Water Works. This infrastructure includes three water treatment plants in the coastal floodplain. These potential impacts could occur now, not at the end of the century or in a future time horizon. These high-risk facilities for flooding will be prioritized for consideration of ongoing and potential further management strategies under Phase 3 of the project. Detailed aerial images with the future floodplains are in Appendix B.

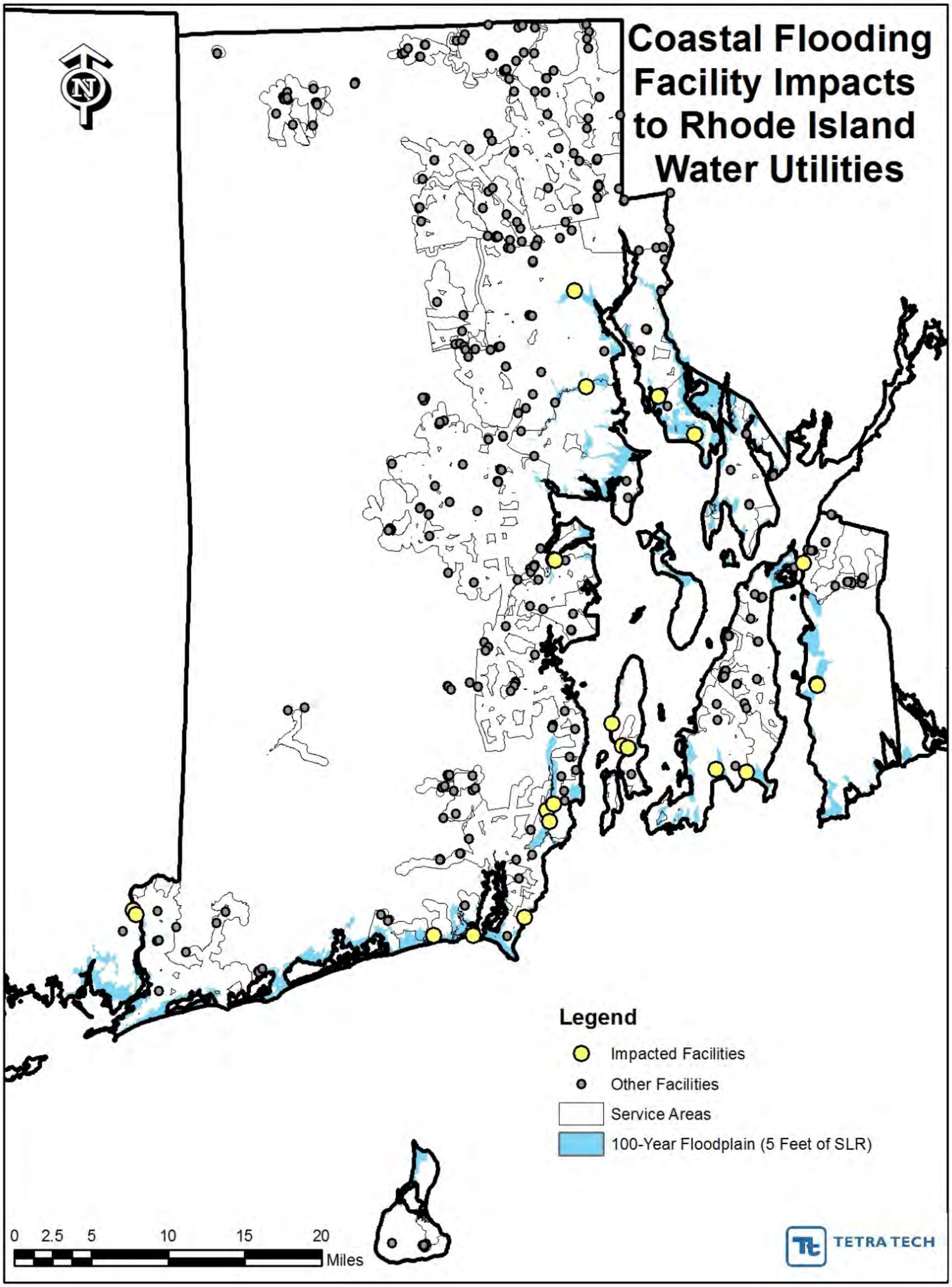


Figure 38. Coastal flooding facility impacts on Rhode Island water utilities.

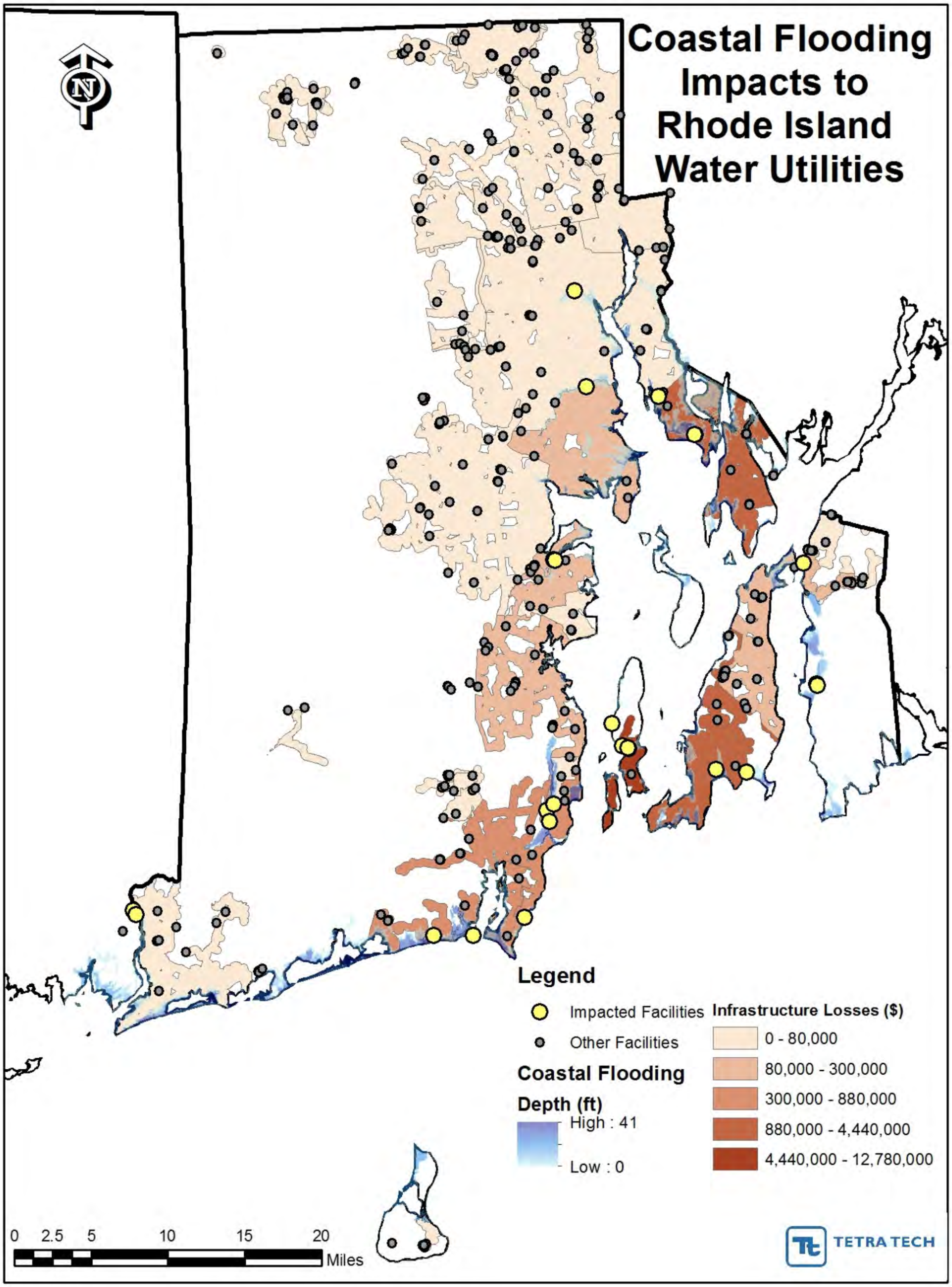


Figure 39. Coastal flooding losses to Rhode Island water utilities.

Table 9. Water utility facility losses (2022)

Name	Type	Value	Distribution	2022 Low Est.		2022 High Est.	
				Depth (ft)	Loss ($)	Depth (ft)	Loss ($)
Nayatt Rd. GW Wells(3)	GW Wells (3)	$2,000,000	Bristol County Water Authority	6.00	$600,000	6.10	$600,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	Bristol County Water Authority	0.00	$0	0.00	$0
Nayatt Road Treatment Plant	Treatment Plant	$5,000,000	Bristol County Water Authority	6.36	$1,500,000	6.46	$1,500,000
Barrington PS	Booster Pump Station	$200,000	Bristol County Water Authority	10.77	$80,000	10.86	$80,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	East Providence Public Works	0.00	$0	0.00	$0
North Kingstown Connection	(E)Emergency Interconnection	$1,000,000	Jamestown Water Division	5.87	$100,000	6.19	$100,000
Jamestown Treatment Facility	Pretreatment Facility	$5,000,000	Jamestown Water Division	0.00	$0	0.00	$0
Jamestown Treatment Plant	Water Treatment Plant	$30,000,000	Jamestown Water Division	5.33	$7,200,000	5.44	$7,200,000
N. Main PS	Booster Pump Station	$200,000	Jamestown Water Division	0.00	$0	0.00	$0
United Water/Narragansett Water	Interconnection	$1,000,000	Narragansett Water Department	18.04	$300,000	18.59	$300,000
SK/Narragansett	Interconnection	$1,000,000	Narragansett Water Department	7.22	$200,000	7.82	$250,000
Sakonnet River Pump Station	Booster Pump Station	$500,000	Newport Water Works	8.49	$200,000	9.01	$200,000
Old Nonquit Pump Station	Booster Pump Station	$200,000	Newport Water Works	10.26	$80,000	10.85	$80,000
Paradise Pump Station	Booster Pump Station	$200,000	Newport Water Works	5.39	$80,000	5.94	$80,000
Newport Water Treatment Plant	Treatment Plant-- Clear Wells	$10,000,000	Newport Water Works	8.08	$3,000,000	8.47	$3,000,000
Newport Low Lift PS	Booster Pump Station	$200,000	Newport Water Works	7.08	$80,000	7.36	$80,000
NK/KCWA	(E)Interconnection	$1,000,000	North Kingstown Water Department	9.70	$300,000	10.08	$300,000
Stone Bridge Fire District	Interconnection	$1,000,000	Portsmouth Water District	4.73	$100,000	5.12	$100,000
Bath St. PS (#3)	Booster Pump Station	$200,000	Providence Water Supply Board	0.00	$0	0.00	$0
SK Booster Pump Station	Booster Pump Station	$200,000	South Kingstown Water Department	0.00	$0	0.00	$0
SK/Middlebridge - UWRI Connection	Interconnection	$1,000,000	South Kingstown Water Department	17.08	$300,000	17.63	$300,000
Interconnection w/Portsmouth	Interconnection	$1,000,000	Stone Bridge Fire District	1.12	$0	7.11	$200,000
Middlebridge to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	17.08	$300,000	17.63	$300,000
Torrey Road to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	6.36	$150,000	6.91	$200,000
Ocean Road to Narragansett	Interconnection	$1,000,000	United Water Rhode Island	0.00	$0	0.00	$0
NK #1 (NK on Forge Rd.)	(E)interconnection	$1,000,000	Warwick Water Department	3.85	$50,000	4.23	$50,000
White Rock Rd. PS #3	Booster Pump Station	$200,000	Westerly Water Department	0.00	$0	0.00	$0
White Rock Rd. PS #1	Booster Pump Station	$200,000	Westerly Water Department	0.00	$0	0.00	$0
					$14,620,000		$14,920,000

Table 10. Water utility facility losses (2052)

Name	Type	Value	Distribution	2052 Low Est.		2052 High Est.	
				Depth (ft)	Loss ($)	Depth (ft)	Loss ($)
Nayatt Rd. GW Wells(3)	GW Wells (3)	$2,000,000	Bristol County Water Authority	6.25	$600,000	7.41	$600,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	Bristol County Water Authority	0.00	$0	0.00	$0
Nayatt Road Treatment Plant	Treatment Plant	$5,000,000	Bristol County Water Authority	6.61	$1,500,000	7.77	$1,500,000
Barrington PS	Booster Pump Station	$200,000	Bristol County Water Authority	11.01	$80,000	12.16	$80,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	East Providence Public Works	0.00	$0	0.00	$0
North Kingstown Connection	(E)Emergency Interconnection	$1,000,000	Jamestown Water Division	6.37	$100,000	7.15	$200,000
Jamestown Treatment Facility	Pretreatment Facility	$5,000,000	Jamestown Water Division	0.00	$0	0.00	$0
Jamestown Treatment Plant	Water Treatment Plant	$30,000,000	Jamestown Water Division	5.55	$9,000,000	6.33	$9,000,000
N. Main PS	Booster Pump Station	$200,000	Jamestown Water Division	0.11	$0	0.89	$0
United Water/Narragansett Water	Interconnection	$1,000,000	Narragansett Water Department	18.77	$300,000	19.86	$300,000
SK/Narragansett	Interconnection	$1,000,000	Narragansett Water Department	8.00	$250,000	9.20	$300,000
Sakonnet River Pump Station	Booster Pump Station	$500,000	Newport Water Works	9.21	$200,000	10.33	$200,000
Old Nonquit Pump Station	Booster Pump Station	$200,000	Newport Water Works	11.01	$80,000	12.20	$80,000
Paradise Pump Station	Booster Pump Station	$200,000	Newport Water Works	5.89	$80,000	6.67	$80,000
Newport Water Treatment Plant	Treatment Plant-- Clear Wells	$10,000,000	Newport Water Works	8.85	$3,000,000	9.85	$4,000,000
Newport Low Lift PS	Booster Pump Station	$200,000	Newport Water Works	7.53	$80,000	8.74	$80,000
NK/KCWA	(E)Interconnection	$1,000,000	North Kingstown Water Department	10.15	$300,000	10.93	$300,000
Stone Bridge Fire District	Interconnection	$1,000,000	Portsmouth Water District	5.23	$100,000	6.01	$150,000
Bath St. PS (#3)	Booster Pump Station	$200,000	Providence Water Supply Board	0.00	$0	0.00	$0
SK Booster Pump Station	Booster Pump Station	$200,000	South Kingstown Water Department	0.00	$0	0.00	$0
SK/Middlebridge - UWRI Connection	Interconnection	$1,000,000	South Kingstown Water Department	17.80	$300,000	18.88	$300,000
Interconnection w/Portsmouth	Interconnection	$1,000,000	Stone Bridge Fire District	7.22	$200,000	7.99	$250,000
Middlebridge to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	17.80	$300,000	18.88	$300,000
Torrey Road to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	7.09	$200,000	8.19	$250,000
Ocean Road to Narragansett	Interconnection	$1,000,000	United Water Rhode Island	0.00	$0	0.00	$0
NK #1 (NK on Forge Rd.)	(E)interconnection	$1,000,000	Warwick Water Department	4.67	$100,000	5.45	$100,000
White Rock Rd. PS #3	Booster Pump Station	$200,000	Westerly Water Department	0.00	$0	0.14	$0
White Rock Rd. PS #1	Booster Pump Station	$200,000	Westerly Water Department	0.00	$0	0.10	$0
					$16,770,000		$18,070,000

Table 11. Water utility facility losses (2084)

Name	Type	Value	Distribution	2084 Low Est.		2084 High Est.	
				Depth (ft)	Loss ($)	Depth (ft)	Loss ($)
Nayatt Rd. GW Wells(3)	GW Wells (3)	$2,000,000	Bristol County Water Authority	7.25	$600,000	7.82	$600,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	Bristol County Water Authority	0.00	$0	0.10	$0
Nayatt Road Treatment Plant	Treatment Plant	$5,000,000	Bristol County Water Authority	7.61	$1,500,000	8.18	$1,500,000
Barrington PS	Booster Pump Station	$200,000	Bristol County Water Authority	11.45	$80,000	12.21	$80,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	East Providence Public Works	0.00	$0	0.10	$0
North Kingstown Connection	(E)Emergency Interconnection	$1,000,000	Jamestown Water Division	7.04	$200,000	9.63	$300,000
Jamestown Treatment Facility	Pretreatment Facility	$5,000,000	Jamestown Water Division	0.00	$0	1.01	$250,000
Jamestown Treatment Plant	Water Treatment Plant	$30,000,000	Jamestown Water Division	6.22	$9,000,000	7.71	$9,000,000
N. Main PS	Booster Pump Station	$200,000	Jamestown Water Division	0.78	$0	2.27	$0
United Water/Narragansett Water	Interconnection	$1,000,000	Narragansett Water Department	14.33	$300,000	21.13	$300,000
SK/Narragansett	Interconnection	$1,000,000	Narragansett Water Department	9.09	$300,000	11.34	$300,000
Sakonnet River Pump Station	Booster Pump Station	$500,000	Newport Water Works	10.16	$200,000	10.85	$200,000
Old Nonquit Pump Station	Booster Pump Station	$200,000	Newport Water Works	12.03	$80,000	12.92	$80,000
Paradise Pump Station	Booster Pump Station	$200,000	Newport Water Works	6.72	$80,000	8.21	$80,000
Newport Water Treatment Plant	Treatment Plant-- Clear Wells	$10,000,000	Newport Water Works	9.68	$4,000,000	11.98	$4,000,000
Newport Low Lift PS	Booster Pump Station	$200,000	Newport Water Works	8.57	$80,000	10.88	$80,000
NK/KCWA	(E)Interconnection	$1,000,000	North Kingstown Water Department	10.76	$300,000	12.25	$300,000
Stone Bridge Fire District	Interconnection	$1,000,000	Portsmouth Water District	5.90	$150,000	7.39	$200,000
Bath St. PS (#3)	Booster Pump Station	$200,000	Providence Water Supply Board	0.00	$0	0.00	$0
SK Booster Pump Station	Booster Pump Station	$200,000	South Kingstown Water Department	0.00	0.00	1.68	$0
SK/Middlebridge - UWRI Connection	Interconnection	$1,000,000	South Kingstown Water Department	18.33	$300,000	20.16	$300,000
Interconnection w/Portsmouth	Interconnection	$1,000,000	Stone Bridge Fire District	7.53	$250,000	8.89	$300,000
Middlebridge to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	18.33	$300,000	20.16	$300,000
Torrey Road to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	7.59	$250,000	9.44	$300,000
Ocean Road to Narragansett	Interconnection	$1,000,000	United Water Rhode Island	0.00	$0	2.65	$0
NK #1 (NK on Forge Rd.)	(E)interconnection	$1,000,000	Warwick Water Department	5.28	$100,000	6.77	$200,000
White Rock Rd. PS #3	Booster Pump Station	$200,000	Westerly Water Department	0.03	$0	1.52	$0
White Rock Rd. PS #1	Booster Pump Station	$200,000	Westerly Water Department	0.00	$0	1.34	$0
					$18,070,000		$18,670,000

Table 12. Water utility facility losses (5 foot sea-level rise)

Name	Type	Value	Distribution	5 Feet SLR Depth (ft)	5 Feet SLR Loss ($)
Nayatt Rd. GW Wells(3)	GW Wells (3)	$2,000,000	Bristol County Water Authority	13.28	$600,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	Bristol County Water Authority	1.77	$0
Nayatt Road Treatment Plant	Treatment Plant	$5,000,000	Bristol County Water Authority	13.68	$2,000,000
Barrington PS	Booster Pump Station	$200,000	Bristol County Water Authority	18.76	$80,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	East Providence Public Works	1.77	$0
North Kingstown Connection	(E)Emergency Interconnection	$1,000,000	Jamestown Water Division	10.61	$300,000
Jamestown Treatment Facility	Pretreatment Facility	$5,000,000	Jamestown Water Division	3.09	$400,000
Jamestown Treatment Plant	Water Treatment Plant	$30,000,000	Jamestown Water Division	9.79	$12,000,000
N. Main PS	Booster Pump Station	$200,000	Jamestown Water Division	4.35	$80,000
United Water/Narragansett Water	Interconnection	$1,000,000	Narragansett Water Department	24.04	$300,000
SK/Narragansett	Interconnection	$1,000,000	Narragansett Water Department	14.56	$300,000
Sakonnet River Pump Station	Booster Pump Station	$500,000	Newport Water Works	11.71	$200,000
Old Nonquit Pump Station	Booster Pump Station	$200,000	Newport Water Works	13.31	$80,000
Paradise Pump Station	Booster Pump Station	$200,000	Newport Water Works	10.29	$80,000
Newport Water Treatment Plant	Treatment Plant-- Clear Wells	$10,000,000	Newport Water Works	15.42	$4,000,000
Newport Low Lift PS	Booster Pump Station	$200,000	Newport Water Works	14.10	$80,000
NK/KCWA	(E)Interconnection	$1,000,000	North Kingstown Water Department	13.45	$300,000
Stone Bridge Fire District	Interconnection	$1,000,000	Portsmouth Water District	9.47	$200,000
Bath St. PS (#3)	Booster Pump Station	$200,000	Providence Water Supply Board	0.93	$0
SK Booster Pump Station	Booster Pump Station	$200,000	South Kingstown Water Department	4.86	$80,000
SK/Middlebridge - UWRI Connection	Interconnection	$1,000,000	South Kingstown Water Department	22.27	$300,000
Interconnection w/Portsmouth	Interconnection	$1,000,000	Stone Bridge Fire District	11.46	$300,000
Middlebridge to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	22.27	$300,000
Torrey Road to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	12.36	$300,000
Ocean Road to Narragansett	Interconnection	$1,000,000	United Water Rhode Island	5.16	$100,000
NK #1 (NK on Forge Rd.)	(E)interconnection	$1,000,000	Warwick Water Department	7.97	$250,000
White Rock Rd. PS #3	Booster Pump Station	$200,000	Westerly Water Department	3.60	$80,000
White Rock Rd. PS #1	Booster Pump Station	$200,000	Westerly Water Department	3.42	$0
					$22,710,000

Table 13. Loss by water utility

	2022 L	2022 H	2052 L	2052 H	2084 L	2084 H	5ft
Distribution	**Loss ($)**	**Loss ($)**	**Loss ($)**	**Loss ($)**	**Loss ($)**	**Loss ($)**	**Loss ($)**
Bristol County Water Authority	$2,180,00	$2,180,00	$2,180,00	$2,180,00	$2,180,00	$2,180,00	$2,680,000
Jamestown Water Division	$7,300,00	$7,300,00	$9,100,00	$9,200,00	$9,200,00	$9,550,00	$12,780,000
Narragansett Water Department	$500,00	$550,00	$550,00	$600,00	$600,00	$600,00	$600,000
Newport Water Works	$3,440,00	$3,440,00	$3,440,00	$4,440,00	$4,440,00	$4,440,00	$4,440,000
North Kingstown Water Department	$300,00	$300,00	$300,00	$300,00	$300,00	$300,00	$300,000
Portsmouth Water District	$100,00	$100,00	$100,00	$150,00	$150,00	$200,00	$200,000
South Kingstown Water Department	$700,00	$700,00	$700,00	$750,00	$750,00	$800,00	$880,000
Stone Bridge Fire District	$0	$200,00	$200,00	$250,00	$250,00	$300,00	$300,000
United Water Rhode Island	$450,00	$500,00	$500,00	$550,00	$550,00	$600,00	$700,000
Warwick Water Department	$50,00	$50,00	$100,00	$100,00	$100,00	$200,00	$250,000
Westerly Water Department	$0	$0	$0	$0	$0	$0	$80,000

6.0 RIVERINE FLOOD ASSESSMENT

Flooding was ranked as a priority hazard in the Rhode Island Hazard Mitigation Plan developed by the Department of Emergency Management (RIEMA 2008). Riverine flooding can be a result of flash flooding, nor'easters, tropical storms, and hurricanes. These events can work alone or together to create coastal flooding in Rhode Island. As the climate changes, increased precipitation, and increased storminess could affect the extent and depth of the coastal floodplains and the resulting damage to water utilities. To better understand the impacts, the future floodplain must be identified.

6.1 Riverine Flood Hazard Assessment

The riverine flood hazard assessment producing future floodplains required three steps: (1) conducting a flood frequency analysis using the climate change results in Section 2.2.2., (2) extrapolating additional flow values for reaches outside the pilot area, and (3) using the flow values in the hydraulic model in HAZUS.

The outputs of the hydrologic modeling described in Section 2.2.2 were used to model extreme events in the pilot basin. 100-year peak flood discharge values for each of the pilot 73 reaches were calculated using standard hydrologic methods described in Bulletin 17B (USWRC 1976). For each time horizon, the GCM and emissions scenario that produced the largest 100-year peak flood discharge was used in the hydraulic model. Because of the limited number of years of data from the climate assessment, the 100-year flood was the largest flood modeled. The 200- or 500-year event would have required many more years of data to assess correctly. The pilot area included a large section of Rhode Island, and the values in the reaches were used to conservatively estimate discharge values for the rest of the state.

The HAZUS-MH approach to hydraulic modeling involves inputting the peak discharges, cross-section descriptions, a 1-D flow field, and Manning's n (from the FEMA Flood Insurance Study) to produce the elevations at cross sections, flood depths, and floodplain boundaries. The three 100-year floodplains developed in HAZUS-MH are shown in Figure 40.

The riverine floodplain modeling methodology produced a flood depth grid which estimates the extents and depth of flooding. These flood depth grids were then overlaid on the water facility data to generate damage and loss estimates. HAZUS-MH provided these loss estimates on the basis of vulnerability functions for water infrastructure; in contrast to sea-level rise where submerged facilities would be lost permanently, the vulnerability functions assume a percent of loss associated with a flood event with infrastructure being repaired following the event. An example of one of these vulnerability functions is shown in Figure 37. The riverine damage functions are not quite as damaging as the coastal because of the wave impact in the coastal areas. The flood loss estimates are discussed in 6.2, Impact Assessment.

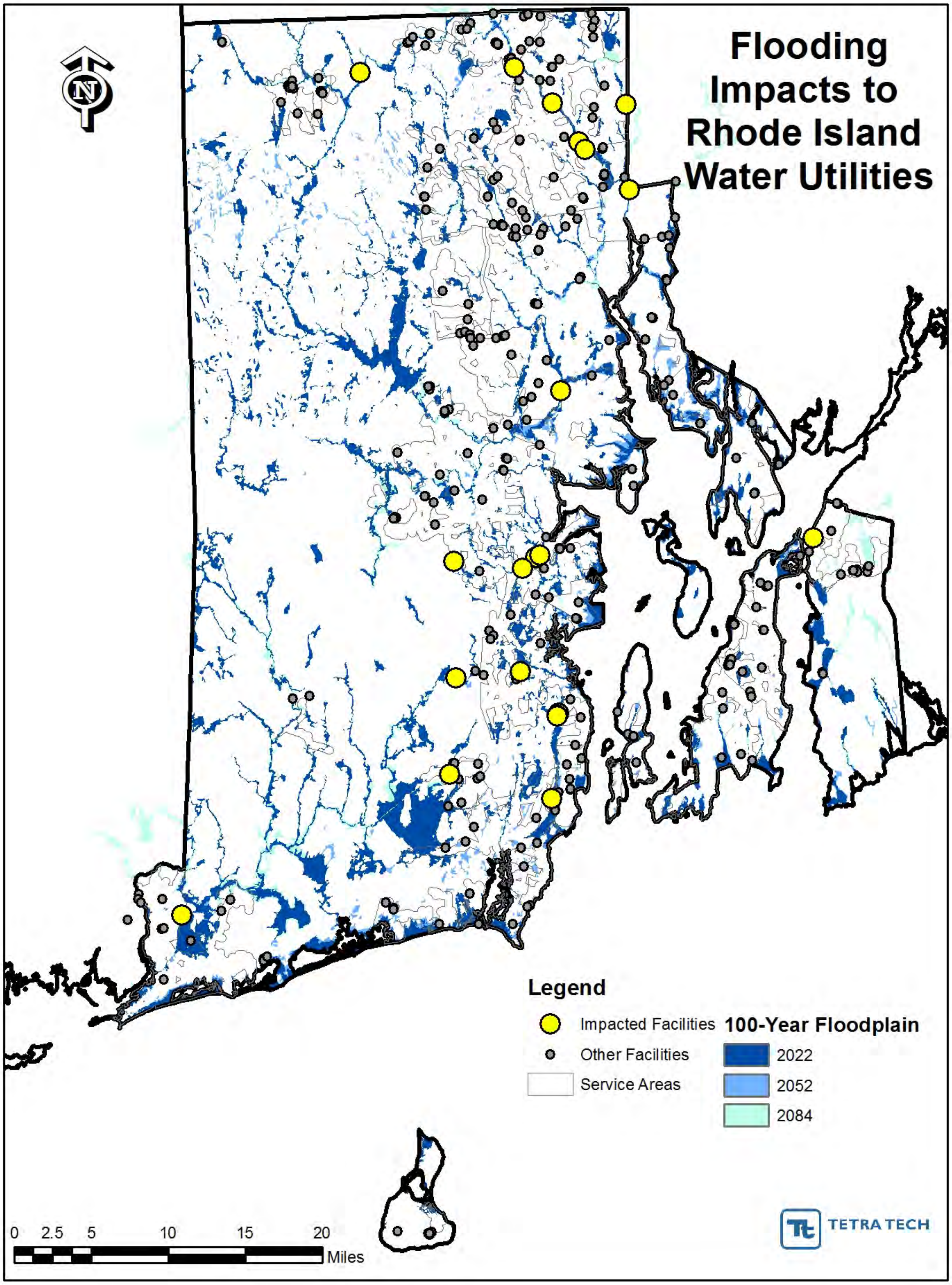


Figure 40. Flooding impacts on Rhode Island water utilities.

6.2 Riverine Flood Impact Assessment

Utility facility data were collected for location, value, and construction type. Losses were calculated for infrastructure in the 100-year riverine floodplain for the three time horizons. Figure 41 shows Rhode Island, the facilities modeled, the coastal and riverine floodplain for the 2084 time horizons, and the loss by water utility. Table 14 identifies the infrastructure affected, the depth of flooding at the site, and loss estimations. Table 15 shows the infrastructure losses by utility.

The results show that wells, booster stations, and interconnections are at risk owned by several utilities. The Rhode Island Economic Development Corporation has the highest loss because of a wells being inundated by more than 16 feet of water and several other wells and pump stations in the floodplain. Many of these potential impacts could occur soon (with the 2022 period) well within the lifespan of the infrastructure. Phase 3 management strategies will focus on reducing the potential risk to these high-risk facilities.

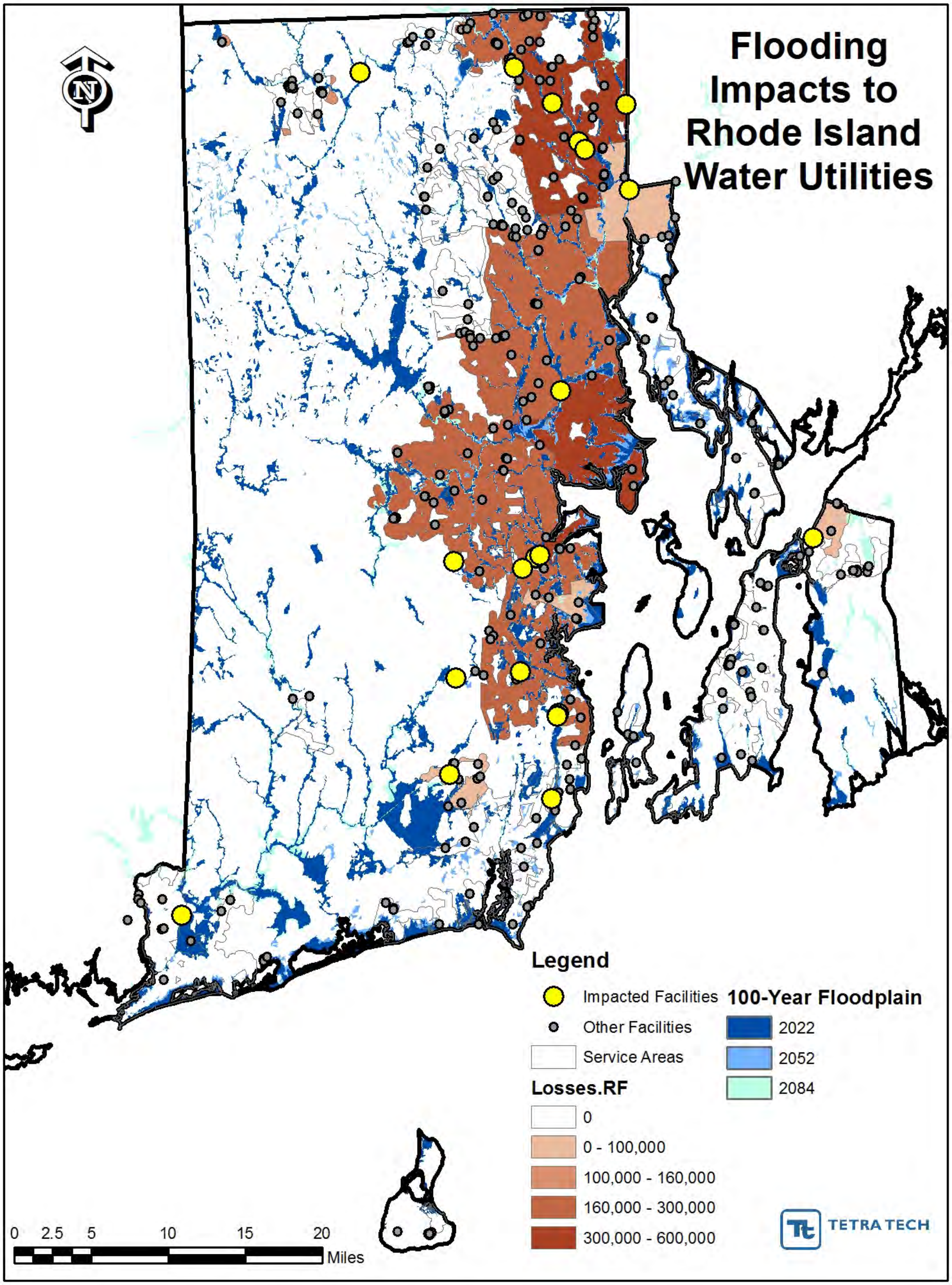


Figure 41. Riverine flood loss (2084).

Table 14. Facility loss

NAME	TYPE	Water Distribution	2022		2052		2084	
			Depth (ft)	Loss ($)	Depth (ft)	Loss ($)	Depth (ft)	Loss ($)
Bradford Tank	Elevated Storage Tank	Westerly Water Department	0.1	$0	0.1	$0	0.1	$0
Carrs Pond Road Tank	Reservoir	Kent County Water Authority	1.4		5.9		5.9	
Branch Street (Pawtucket)	Booster Pump Station	Pawtucket Water Supply Board	0.0	$0	26.1	$80,000	26.1	$80,000
RIEDC #4	Booster Pump Station	RI Economic Development Corp.	1.9	$0	4.3	$80,000	4.3	$80,000
RIEDC #1	Booster Pump Station	RI Economic Development Corp.	0.9	$0	3.0	$0	3.0	
Carey Lane Booster Pump Station #3	Booster Pump Station	North Tiverton Fire District	18.2	$80,000	18.2	$80,000	18.2	$80,000
NK Pump Station#2	Booster Pump Station	North Kingstown Water Department	3.2	$0	3.2	$0	8.3	$80,000
NK Pump Station#10	Booster Pump Station	North Kingstown Water Department	2.1	$0	2.2	$0	6.3	$80,000
NK Pump Station#9	Booster Pump Station	North Kingstown Water Department	1.5	$0	3.0	$0	3.0	$0
NK Pump Station#3	Booster Pump Station	North Kingstown Water Department	3.3	$0	3.3	$0	3.3	$0
NK Pump Station#7	Booster Pump Station	North Kingstown Water Department	5.1	$80,000	5.3	$80,000	5.3	$80,000
NK Pump Station#8	Booster Pump Station	North Kingstown Water Department	2.5	$0	2.5	$0	2.5	$0
RIEDC Well #2	Gravel Packed Well	RI Economic Development Corp.	1.1	$8,000	2.5	$40,000	2.5	$40,000
RIEDC Well #3	Gravel Packed Well	RI Economic Development Corp.	1.9	$16,000	4.2	$160,000	4.2	$160,000
East Greenwich Well	Gravel Packed Well	Kent County Water Authority	3.7	$160,000	7.3	$240,000	13.5	$240,000
Lincoln/Woonsocket Interconnection	Interconnection	Woonsocket Public Works Dept.	0.0	$0	23.0	$300,000	23.0	$300,000
PWSB #2 (Pettaconsett Av. at Pawtuxet Ri	Interconnection (30 inch.)	Warwick Water Department	0.0	$0	11.5	$600,000	11.5	$600,000
SK/Narragansett -- Torrey Rd.	Interconnection	South Kingstown Water Department	0.0	$0	5.1	$100,000	5.1	$100,000
Warwick/PWSB -- Pettaconsett	Interconnection	Providence Water Supply Board	0.0	$0	11.1	$300,000	11.1	$300,000
KCWA Post Road Cross-Connection	Interconnection	RI Economic Development Corp.	1.6	$0	5.7	$150,000	5.7	$150,000
Cumberland/Lincoln	Interconnection (20inch.)	Lincoln Water Commission	13.9	$450,000	13.9	$450,000	21.0	$450,000
Well #2	Water Wells	Harrisville Fire District	0.0	$0	3.9	$160,000	3.9	$160,000
Abbott RunWell#2&#3	Water Wells	Cumberland Water Department	15.9	$450,000	15.9	$450,000	15.9	$450,000
Martin St. PS	Booster Pump Station	Cumberland Water Department	2.1	$0	2.1	$0	4.4	$80,000
PS #1 & #6	Booster Pump Station	Lincoln Water Commission	2.7	$0	2.7	$0	5.9	$80,000
E. Greenwich Well 3	Water Wells	RI Economic Development Corp.	1.9	$8,000	4.3	$160,000	4.3	$160,000
RIEDC #1 PS	Booster Pump Station	RI Economic Development Corp.	0.9	$0	3.0	$0	3.0	$0
Well #1	Water Wells	RI Economic Development Corp.	16.3	$240,000	16.3	$240,000	16.3	$240,000
Pump Station	Booster Pump Station	Kingston Water District	0.0	$0	9.3	$80,000	9.3	$80,000
				$1,492,000		$3,750,000		$4,070,000

Table 15. Loss by utility

Distribution	2022 Loss ($)	2052 Loss ($)	2084 Loss ($)
Cumberland Water Department	$450,000	$450,000	$530,000
Harrisville Fire District	$0	$160,000	$160,000
Kent County Water Authority	$160,000	$240,000	$240,000
Kingston Water District	$0	$80,000	$80,000
Lincoln Water Commission	$450,000	$450,000	$530,000
North Kingstown Water Department	$80,000	$80,000	$240,000
North Tiverton Fire District	$80,000	$80,000	$80,000
Pawtucket Water Supply Board	$0	$80,000	$80,000
Providence Water Supply Board	$0	$300,000	$300,000
RI Economic Development Corp.	$352,000	$1,290,000	$1,290,000
South Kingstown Water Department	$0	$100,000	$100,000
Warwick Water Department	$0	$600,000	$600,000
Woonsocket Public Works Dept.	$0	$300,000	$300,000

7.0 HURRICANE ASSESSMENT

Wind-related hazards rank as the number two priority hazard in the *Rhode Island Hazard Mitigation Plan* (RIEMA 2008). NOAA defines hurricanes as non-frontal, low-pressure, synoptic-scale systems that develop over tropical or subtropical water and have definite organized circulations.[7] As the climate changes, sea-level rise and increased storminess could affect the magnitudes of the hurricanes. To better understand the impacts, the future storm surge area and probable wind speeds need to be identified.

7.1 Hurricane Hazard Assessment

The hurricane hazard assessment integrates data on sea-level rise (described in Section 4), coastal erosion (collected from CRMP), and NOAA tidal data into a hurricane surge model. Surge areas were developed for 100-year events at three time horizons (2022, 2052, and 2084) for low and high scenarios and for the 5-foot sea-level rise scenario. Current hurricane wind speeds were identified using the probabilistic 100-year wind speeds developed by the American Society of Civil Engineers (ASCE) for the state on the basis of Census Tract (see Figure 42). This approach of assigning the wind speeds to the Census Tract was adopted for this project due to the HAZUS-MH methodology based on the ASCE data. These wind speeds equate to a category 2 hurricane. These wind speeds were increased to a category 3 event for the 2052 scenario and to a category 4 event for the 2084 scenario to simulate increased magnitude due to warmer oceans. As presented in Section 2, climate models generally consistently predict steady increases in temperature. It is likely that hurricane/typhoon wind speeds and core rainfall rates will increase in response to human-caused warming. Analyses of model simulations suggest that for each 1 °C increase in tropical sea surface temperatures, hurricane surface wind speeds will increase by 1 to 8 percent and core rainfall rates by 6 to 18 percent (CCSP and Subcommittee on Global Change Research 2008).

FEMA's HAZUS-MH software including the Simulating WAves Nearshore (SWAN) and Sea, Lake, and Overland Surges from Hurricanes (SLOSH) models were used to predict the extent and depth of the coastal surge. Figure 43 shows the modeled hurricane wind speeds and storm surge for the 2052 event, and Figure 44 shows the modeled hurricane wind speeds and storm surge for the 2084 event. The 2022 event was considered very close to the present-day event and was not modeled. Appendix E provides detailed maps of the areas impacted by hurricane surge.

[7] As defined online at: http://www.aoml.noaa.gov/hrd/tcfaq/A1.html.

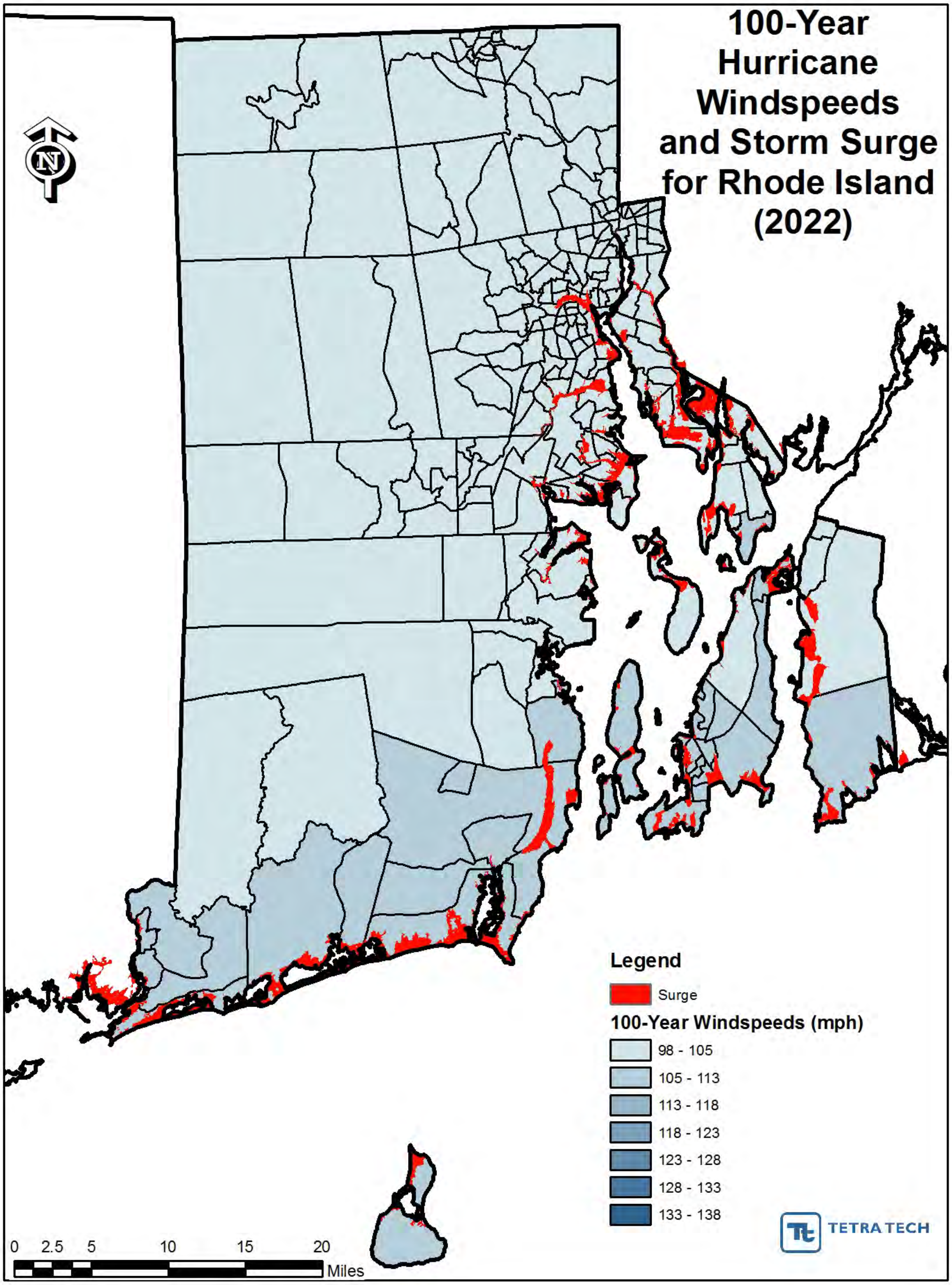


Figure 42. 100-Year hurricane wind speeds (by Census Tract) and storm surge for Rhode Island.

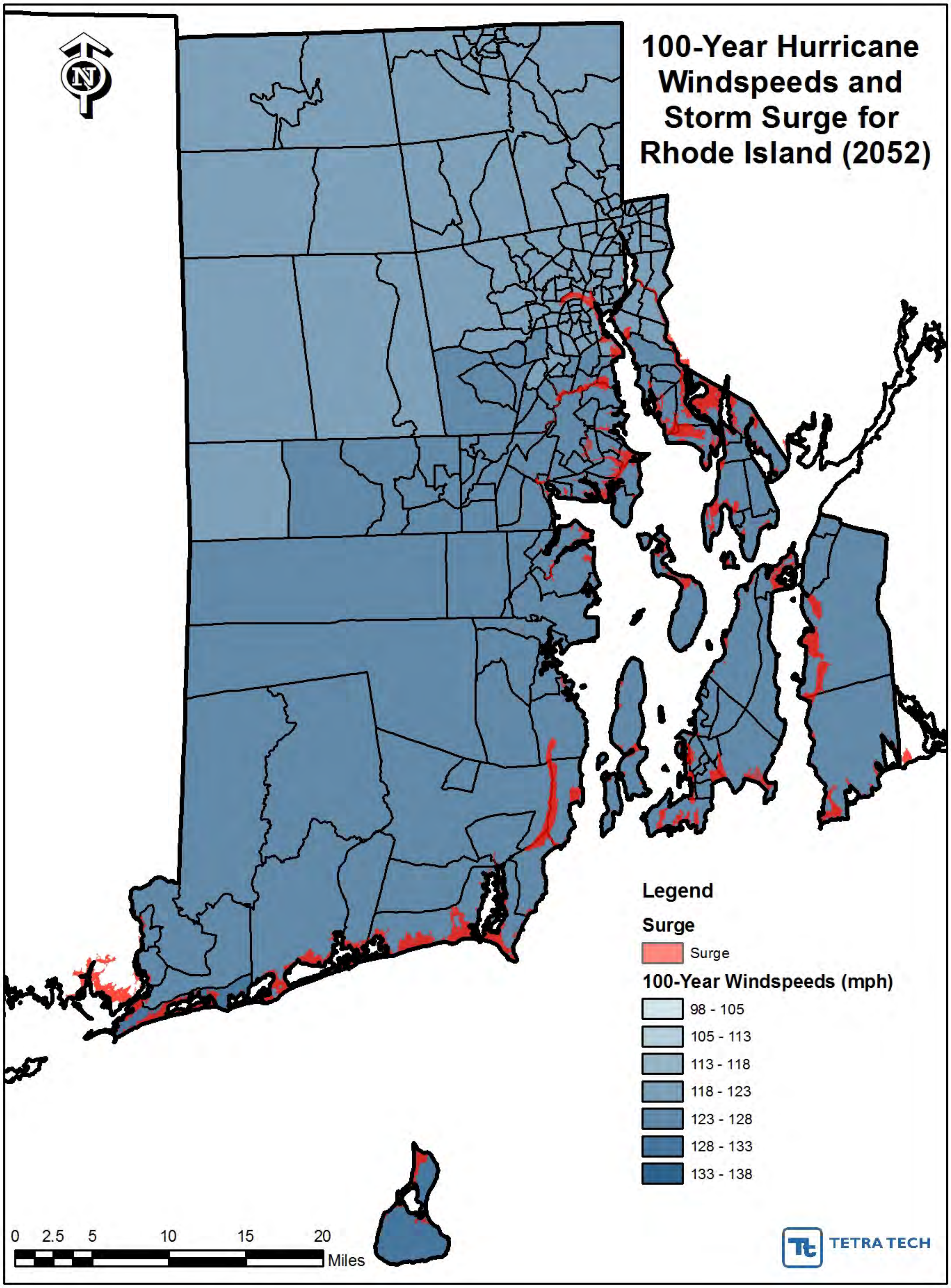


Figure 43. 100-Year hurricane wind speeds (by Census Tract) and storm surge for Rhode Island (2052).

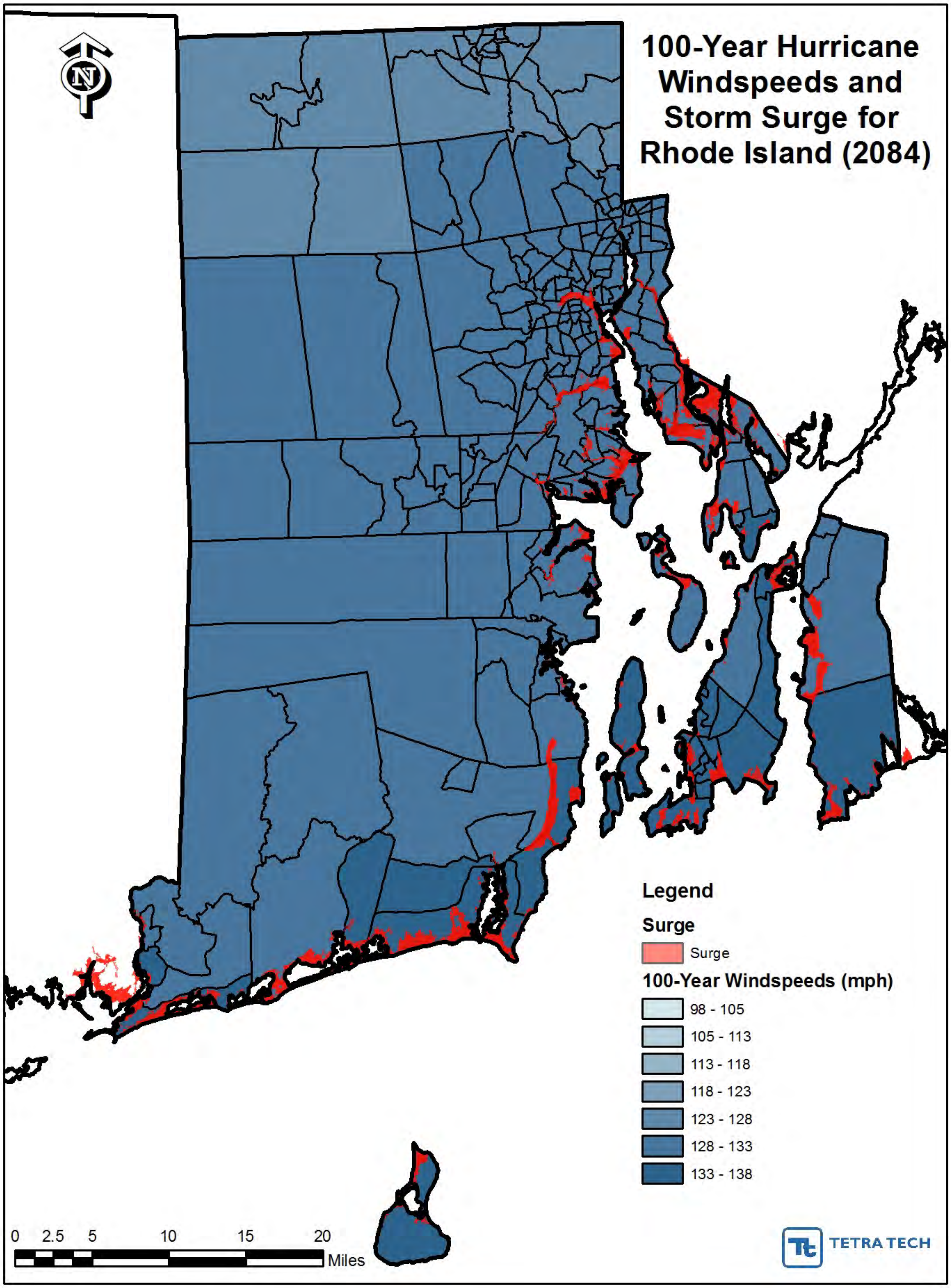


Figure 44. 100-Year hurricane wind speeds (by Census Tract) and storm surge for Rhode Island (2084).

The hurricane model in HAZUS-MH also contains wind damage functions, similar to the flood damage functions. These functions convert the peak gust wind speed into a loss ratio. An example of a wind damage function is shown in Figure 45. The functions are based on the terrain around the facility. In the example shown in Figure 45, a 160 mph wind speed would produce 30% damage in a forested area and 69% damage in an open area.

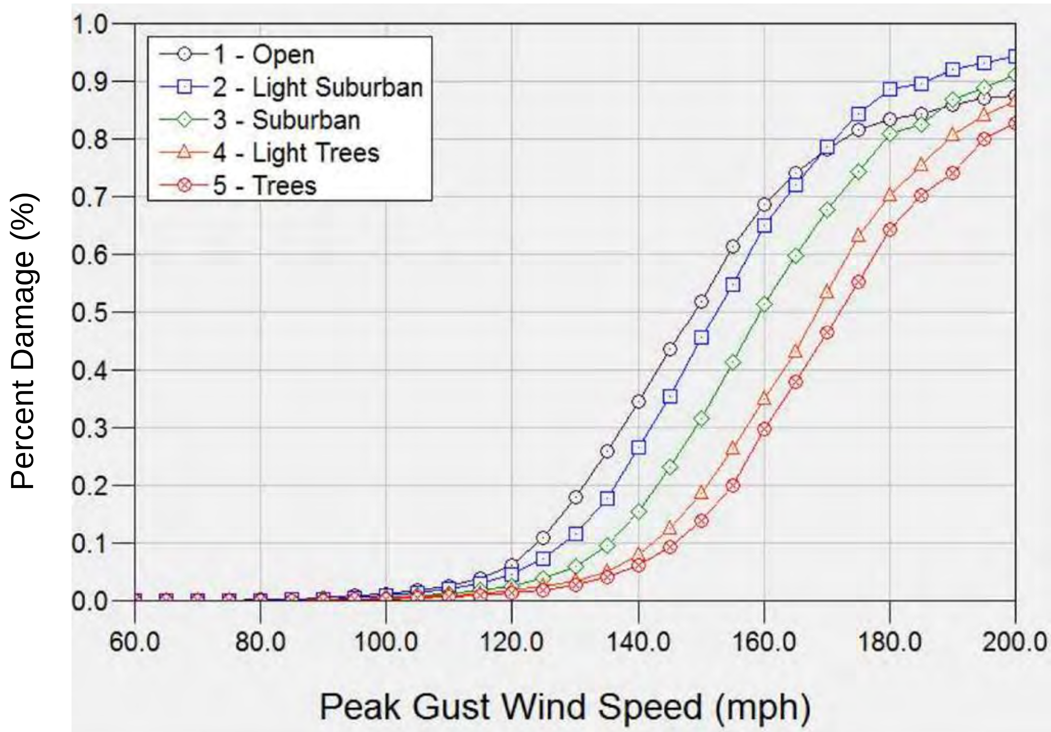


Figure 45. Wind speed damage function.

To prevent double counting damage, the HAZUS-MH model has a matrix for each facility type that is based on the amount of damage received from wind or flood. An example of one of the matrices is in Figure 46.

		Flood Damage										
		0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Wind Damage	**0%**	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	10%	10%	20%	29%	38%	47%	56%	65%	75%	84%	94%	100%
	20%	20%	29%	38%	46%	54%	63%	71%	79%	89%	99%	100%
	30%	30%	39%	47%	55%	62%	70%	78%	86%	95%	100%	100%
	40%	40%	48%	56%	63%	70%	77%	84%	91%	100%	100%	100%
	50%	50%	58%	65%	71%	78%	84%	90%	97%	100%	100%	100%
	60%	60%	68%	74%	79%	85%	91%	96%	100%	100%	100%	100%
	70%	70%	77%	82%	88%	93%	97%	100%	100%	100%	100%	100%
	80%	80%	87%	91%	96%	100%	100%	100%	100%	100%	100%	100%
	90%	90%	96%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 46. Hurricane loss matrix.

7.2 Hurricane Impact Assessment

Utility facility data were collected for location, value, and construction type. Losses were calculated for infrastructure in storm surge inundation areas for the three time horizons and the 5-foot prediction. Figure 47 shows Rhode Island and the loss by water utility for the 2084 event. Table 16 identifies the infrastructure affected and the loss estimations due to flood and wind. For each time horizon, there is a low and high estimation of sea level rise. Appendix B depicts the coastal floodplain around 28 at-risk facilities. Table 17 shows the infrastructure losses by utility.

The results show that although all water utilities would be affected from a powerful hurricane because of the wind speed, 12 utilities would be affected by the storm surge as well. Three water treatment plants would be substantially damaged from a hurricane. The Jamestown Water Division, Newport Water Works, and Bristol County Water Authority would have the greatest losses.

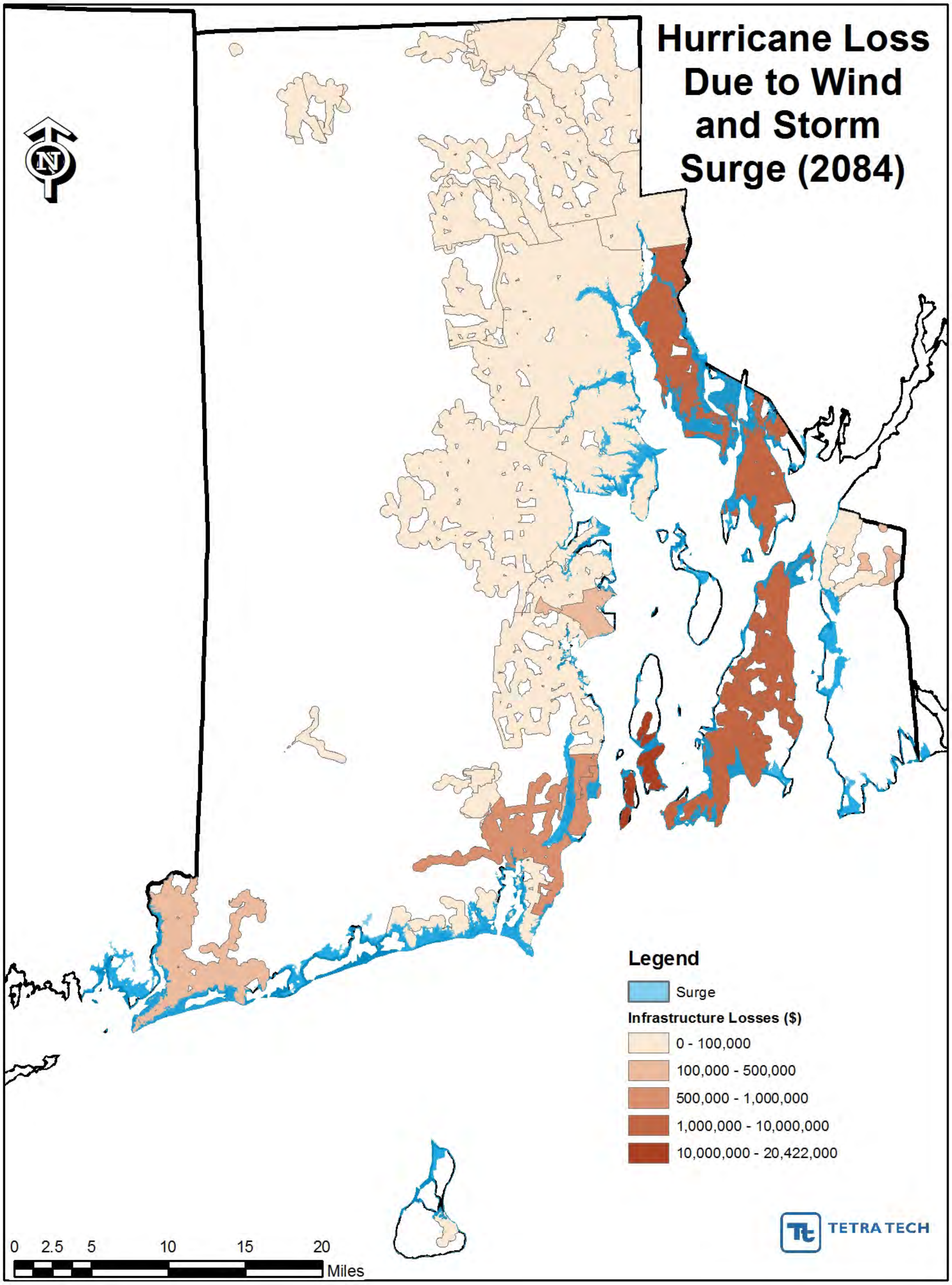


Figure 47. Hurricane loss due to storm surge and wind.

Table 16. Facility loss due to storm surge and wind

Name	Type	Value	Distribution	2022		2052		2084		Five Feet	
				mph	Loss ($)	mph	Loss ($)	mph	Loss ($)	mph	Loss ($)
Nayatt Rd. GW Wells(3)	GW Wells (3)	$2,000,000	Bristol County Water Authority	103.00	$620,000	125.00	$760,000	131.00	$1,080,000	131.00	$1,080,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	Bristol County Water Authority	103.00	$0	124.00	$0	130.00	$0	130.00	$0
Nayatt Road Treatment Plant	Treatment Plant	$5,000,000	Bristol County Water Authority	103.00	$1,550,000	125.00	$1,900,000	131.00	$2,700,000	131.00	$3,050,000
Barrington PS	Booster Pump Station	$200,000	Bristol County Water Authority	103.00	$82,000	125.00	$96,000	131.00	$122,000	131.00	$122,000
BCWA INTERCONNECTION	Interconnection	$1,000,000	East Providence Public Works	103.00	$0	124.00	$0	130.00	$0	130.00	$0
North Kingstown Connection	(E)Emergency Interconnection	$1,000,000	Jamestown Water Division	106.00	$100,000	127.00	$200,000	134.00	$300,000	134.00	$300,000
Jamestown Treatment Facility	Pretreatment Facility	$5,000,000	Jamestown Water Division	106.00	$150,000	127.00	$600,000	134.00	$1,550,000	134.00	$1,700,000
Jamestown Treatment Plant	Water Treatment Plant	$30,000,000	Jamestown Water Division	106.00	$6,900,000	127.00	$11,400,000	134.00	$16,200,000	134.00	$18,300,000
N. Main PS	Booster Pump Station	$200,000	Jamestown Water Division	106.00	$6,000	127.00	$24,000	134.00	$56,000	134.00	$122,000
United Water/Narragansett Water	Interconnection	$1,000,000	Narragansett Water Department	107.00	$250,000	128.00	$300,000	135.00	$300,000	135.00	$300,000
SK/Narragansett	Interconnection	$1,000,000	Narragansett Water Department	107.00	$300,000	128.00	$300,000	135.00	$300,000	135.00	$300,000
Sakonnet River Pump Station	Booster Pump Station	$500,000	Newport Water Works	104.00	$205,000	125.00	$240,000	133.00	$305,000	133.00	$305,000
Old Nonquit Pump Station	Booster Pump Station	$200,000	Newport Water Works	104.00	$82,000	125.00	$96,000	133.00	$122,000	133.00	$122,000
Paradise Pump Station	Booster Pump Station	$200,000	Newport Water Works	106.00	$84,000	126.00	$96,000	134.00	$122,000	134.00	$122,000
Newport Water Treatment Plant	Treatment Plant-- Clear Wells	$10,000,000	Newport Water Works	106.00	$3,200,000	127.00	$4,800,000	134.00	$6,100,000	134.00	$6,100,000
Newport Low Lift PS	Booster Pump Station	$200,000	Newport Water Works	106.00	$84,000	127.00	$96,000	134.00	$122,000	134.00	$122,000
NK/KCWA	(E)Interconnection	$1,000,000	North Kingstown Water Department	104.00	$300,000	125.00	$300,000	131.00	$300,000	131.00	$300,000
Stone Bridge Fire District	Interconnection	$1,000,000	Portsmouth Water District	104.00	$100,000	125.00	$150,000	132.00	$200,000	132.00	$200,000
Bath St. PS (#3)	Booster Pump Station	$200,000	Providence Water Supply Board	102.00	$6,000	123.00	$24,000	128.00	$56,000	128.00	$56,000
SK Booster Pump Station	Booster Pump Station	$200,000	South Kingstown Water Department	106.00	$6,000	127.00	$24,000	134.00	$56,000	134.00	$122,000
SK/Middlebridge - UWRI Connection	Interconnection	$1,000,000	South Kingstown Water Department	107.00	$300,000	128.00	$300,000	135.00	$300,000	135.00	$300,000
Interconnection w/Portsmouth	Interconnection	$1,000,000	Stone Bridge Fire District	104.00	$200,000	125.00	$250,000	132.00	$300,000	132.00	$300,000
Middlebridge to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	107.00	$300,000	128.00	$300,000	135.00	$300,000	135.00	$300,000
Torrey Road to South Kingstown	Interconnection	$1,000,000	United Water Rhode Island	107.00	$200,000	128.00	$250,000	135.00	$300,000	135.00	$300,000
Ocean Road to Narragansett	Interconnection	$1,000,000	United Water Rhode Island	107.00	$0	128.00	$0	135.00	$0	135.00	$100,000
NK #1 (NK on Forge Rd.)	(E)Interconnection	$1,000,000	Warwick Water Department	104.00	$50,000	125.00	$100,000	131.00	$200,000	131.00	$250,000
White Rock Rd. PS #3	Booster Pump Station	$200,000	Westerly Water Department	105.00	$6,000	126.00	$24,000	132.00	$56,000	132.00	$122,000
White Rock Rd. PS #1	Booster Pump Station	$200,000	Westerly Water Department	105.00	$6,000	126.00	$24,000	132.00	$56,000	132.00	$56,000
					$15,087,000		$22,654,000		$31,503,000		$34,451,000

Table 17. Total loss by utility

Distribution	2022 Loss ($)	2052 Loss ($)	2084 Loss ($)	Five Feet Loss ($)
Bristol County Water Authority	$2,252,000	$2,756,000	$3,902,000	$4,252,000
East Providence Public Works	$0	$0	$0	$0
Jamestown Water Division	$7,156,000	$12,224,000	$18,106,000	$20,422,000
Narragansett Water Department	$550,000	$600,000	$600,000	$600,000
Newport Water Works	$3,655,000	$5,328,000	$6,771,000	$6,771,000
North Kingstown Water Department	$300,000	$300,000	$300,000	$300,000
Portsmouth Water District	$100,000	$150,000	$200,000	$200,000
Providence Water Supply Board	$6,000	$24,000	$56,000	$56,000
South Kingstown Water Department	$306,000	$324,000	$356,000	$422,000
Stone Bridge Fire District	$200,000	$250,000	$300,000	$300,000
United Water Rhode Island	$500,000	$550,000	$600,000	$700,000
Warwick Water Department	$50,000	$100,000	$200,000	$250,000
Westerly Water Department	$12,000	$48,000	$112,000	$178,000

8.0 NEXT STEPS

The *Safe***Water** RI project is iterative, with each phase building on the previous phase(s). The Phase 1 data collection efforts established a baseline of understanding of the viewpoints and activities of water utility partners; the Phase 2 impact assessment identified the priority vulnerabilities and risks to water utility infrastructure. Both phases will be used to inform the remaining *Safe***Water** RI project phases. For example, identifying priority issues and key challenges of the water utilities in Phase 2 will assist in developing appropriate adaptation options (Phase 3: Development of Management Strategies), and understanding the utility stakeholder perceptions of climate change and extreme weather will assist in developing education and outreach strategies (Phase 4: Outreach and Education). Developing and maintaining relationships with the water utility partners will also assist in facilitating the ultimate *buy-in* for project recommendations.

Rhode Island has taken actions to address the potential impacts of hazards such as coastal erosion and, with this study, is taking action to plan for the potential exacerbating impacts of climate change on priority hazards that can affect the water supply system. The effects of extreme hazard events and changes in water availability require planning for water supply to ensure structures can withstand higher flood waters and to prepare for erosion, storm surge, sea level rise, and increased flooding.

Climate change challenges elevate the importance of managing water in an integrated manner so that adequate supplies are available for the population. While the water utilities might be able to manage in isolation in the face of climate change, the system operates within the larger basin and water-related challenges would be exacerbated by climate change impacts. The impacts of climate change, population growth, and development, will affect water utility operations in the future.

Given the need to plan for climate change in the face of a number of uncertainties, the Phase 3 portion of this project will focus on management strategies that build on, or align with, other water system natural hazard, economic, social, or environmental issues. Challenges in these areas (e.g., increasing demand for water, sea-level rise/erosion, development in areas with high-risk water systems) can be exacerbated by the climate change impacts identified by this study. Tackling high-priority challenges using management strategies with multiple benefits supports planning for the future in a way that is beneficial regardless of whether the anticipated climate change affects drinking water utility assets as modeled.

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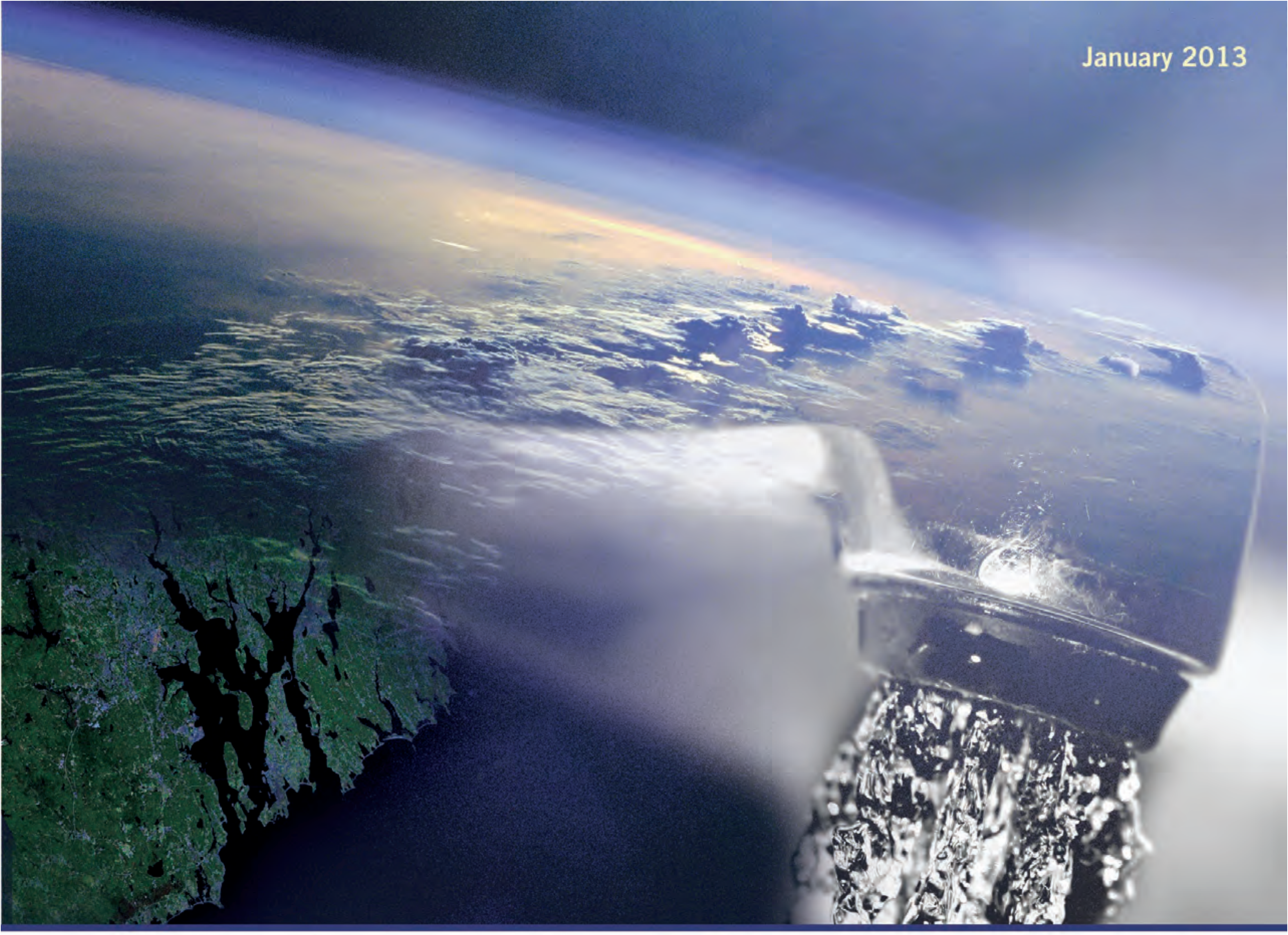

SafeWater RI

ENSURING SAFE WATER FOR RHODE ISLAND'S FUTURE

Phase 3 Report
Adaptation Strategies

Prepared for:
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RHODE ISLAND DEPARTMENT OF HEALTH

TETRA TECH

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1.0 BACKGROUND AND OVERVIEW

Drinking water utilities in Rhode Island face numerous challenges such as drought, pollution, competing water uses, and aging infrastructure that must be addressed to ensure that their customers receive safe, dependable drinking water. The potential impacts from global climate change could exacerbate current challenges and present new risks to Rhode Island water utilities and their service areas.

Altered precipitation patterns could increase flood events, like the recent flooding experienced in 2010; more extreme weather events could pose storm surge risks to the state's more than 400 miles of coastline. In addition to physical damage to water infrastructure systems and dams, flooding could also increase turbidity and pollutant loads in source water, requiring more extensive treatment to remove the pollutants. Excessive flooding could also release pathogens from storm sewer systems if their capacity to manage wastewater were exceeded during storm events. Areas that rely heavily on wells, such as the eastern portion of the state, could become contaminated by surface water containing pathogenic protozoa such as *Giardia* and *Cryptosporidium*. Additionally, the global melting of glaciers and ice sheets, coupled with the thermal expansion of ocean volume as water temperatures increase, could affect coastal areas through sea-level rise. Elevated sea levels could contaminate aquifers through intrusion of saltwater and damage coastal ecosystems, which could be particularly challenging for Rhode Island because the majority of the population lives along the coastline.

To help respond to these challenges, the Rhode Island Department of Health (HEALTH), Office of Drinking Water Quality, launched *Safe***Water** RI*: Ensuring Safe Water for Rhode Island's Future* (*Safe***Water** RI) in January 2012. The project will help address the implications of climate change for drinking water utilities by providing locally relevant and actionable data for water utility managers to evaluate and plan for future scenarios. The objective of the project is to assess changing environmental conditions (including temperature, precipitation patterns, sea-level rise, and storm surge) and their potential impacts on drinking water utilities in Rhode Island to develop strategies to address such changing conditions. The *Safe***Water** RI project has four project components:

- Phase 1: Data Collection
- Phase 2: Assessment of Impacts
- Phase 3: Development of Management Strategies
- Phase 4: Outreach and Education

This report builds on the Phase 2 impact assessment findings, which identified the vulnerabilities and risks to water utility infrastructure. This report aims to develop climate change adaptation strategies and a framework for implementation.

1.1 Introduction

As identified in Phase 2 of this project, climate change will present many challenges to Rhode Island water utilities. Climate change will increase air temperature and alter precipitation patterns, with more extreme precipitation events anticipated for the future. The Pawtuxet River Basin will experience an increase in the total average annual flow volume in the future, while the state could also experience more intense droughts. The water utility infrastructure impact assessment showed that water utilities are at-risk from sea-level rise, hurricanes, and coastal and riverine flooding.

Effective responses to these challenges must be identified, evaluated, prioritized and implemented in a manner that achieves two primary goals: (1) addressing the most threatening and urgent concerns as promptly and effectively as possible and (2) implementing those responses that have multiple benefits and/or are most cost-effective in order to minimize overall adaptation costs and maximize benefits. This report identifies adaptation goals and provides a framework for consideration of adaptation strategies that can be refined within the context of each water utility and with stakeholder input over time.

The Phase 3 report is organized according to the following:

- Section 1: Background and Overview
- Section 2: Priority Vulnerabilities
- Section 3: Adaptation Goals
- Section 4: Adaptation Strategies
- Section 5: Structured Decision-Making
- Section 6: Next steps

Section 2 identifies the priority vulnerabilities and risks associated with the 35 major municipal and private water suppliers based on the impact assessment conducted in Phase 2. Section 3 defines and presents adaptation goals that are based on those identified in Rhode Island's drinking water state-guide plan, *Rhode Island Water 2030*. The goals are focused on the steps water utilities may take to adapt to climate change using their own assets, while also supporting state-wide initiatives. Section 4 presents adaptation strategies to meet the adaptation goals and provides a framework for evaluating adaptation strategies using specific evaluation criteria. Section 5 illustrates a structured decision-making framework that drinking water utilities can take to tailor the adaptation goals and strategies presented in this report to their specific circumstances. Section 6 identifies the final activities of the *Safe***Water** RI project.

2.0 PRIORITY VULNERABILITIES

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the extent of susceptibility of a system to sustaining damage from climate change (IPCC 2001). "Susceptibility to damage" encompasses not only the risk to a system, but also the resilience of the system to persist in the face of that risk. Vulnerability is thus considered a function of sensitivity of the system to climate change, of degree of exposure to climate hazards, and of adaptive capacity[1] (IPCC 2001). The application of vulnerability to the *Safe***Water** RI project will be further detailed in this section.

The impact assessment conducted as Phase 2 of the *Safe***Water** RI project evaluated responses to potential future climates using 24 scenarios, which are based on four Global Climate Models (GCMs), and under two greenhouse gas emissions scenarios (A2 and B1).[2] Using an approach that evaluates a number of scientifically plausible future states allows an assessment of the sensitivity of the system to climate change. Climate scenario changes were then statistically downscaled so that the GCM output would be at

[1] Adaptive capacity is defined by the IPCC as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2001).

[2] The A2 emission scenario family assumes a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. The B1 scenario family is near the lower limit of projected changes in greenhouse gas emissions. The B1 scenario family assumes global population growth peaks by mid-century and then declines, a rapid economic shift toward service and information economies, and the introduction of clean and resource-efficient technologies. For more information on emission scenarios, see the IPCC website http://sedac.ipcc-data.org/ddc/sres/index.html

a smaller spatial scale. This approach provides more locally-relevant climate change data for Rhode Island than other climate change assessments have used to date.

A hazards and risk assessment was then conducted under Phase 2, to assess the climate change impacts of five hazards (drought, riverine and coastal flooding, sea level inundation, and hurricanes) on the 34 major water utilities in the state, which provide water for over 90 percent of the population of the state. Figure 1 presents the 34 major water utilities and their service areas considered for the impact assessment. Those water utilities that could suffer asset damage/loss were identified for each hazard, and for each future time horizon (2022, 2052, and 2084). The projected future impact of each hazard relative to the location of the 34 largest drinking water utilities determined the exposure, while the degree of at-risk infrastructure determined the susceptibility of the water utility for each hazard. The objective of the impact assessment was to provide site-specific information for each of the 34 major water utilities in the state so that water managers can evaluate the degree of risk and specific asset loss for their utility.

Overwhelmingly, the results from Phase 2 show that water managers can no longer assume that future climate and hydrologic patterns will resemble those of the past. Indeed, recent studies have found that the pace of climate change seems to be accelerating and closer to the "worst case" IPCC scenarios. The National Center for Atmospheric Research determined that global warming is likely to be on the high side of the IPCC projections (Vastag 2012). Figure 2 illustrates the projected increase in carbon dioxide (CO_2) emissions from fossil fuels in five of the emissions scenarios used by the IPCC, compared to the International Energy Agency's (IEA's) actual observational CO_2 emissions data from fossil fuel consumption, to underscore this point. Additionally, a recent report from the National Oceanic and Atmospheric Administration (NOAA) finds that global mean sea level will rise at least 8 inches, and possibly up to 6.6 feet (2 meters) by 2100 (NOAA 2012). Thus, the modeled results from Phase 2 of the *Safe***Water** RI project, as well ongoing domestic and international climate change studies that show possible acceleration in emissions rates and sea level rise, illustrate the importance of including consideration of climate change impacts in water utility planning.

This report will further explore the concept of adaptive capacity, and will identify the management strategies and adaption options available for the water utilities to increase their overall resilience to climate change.

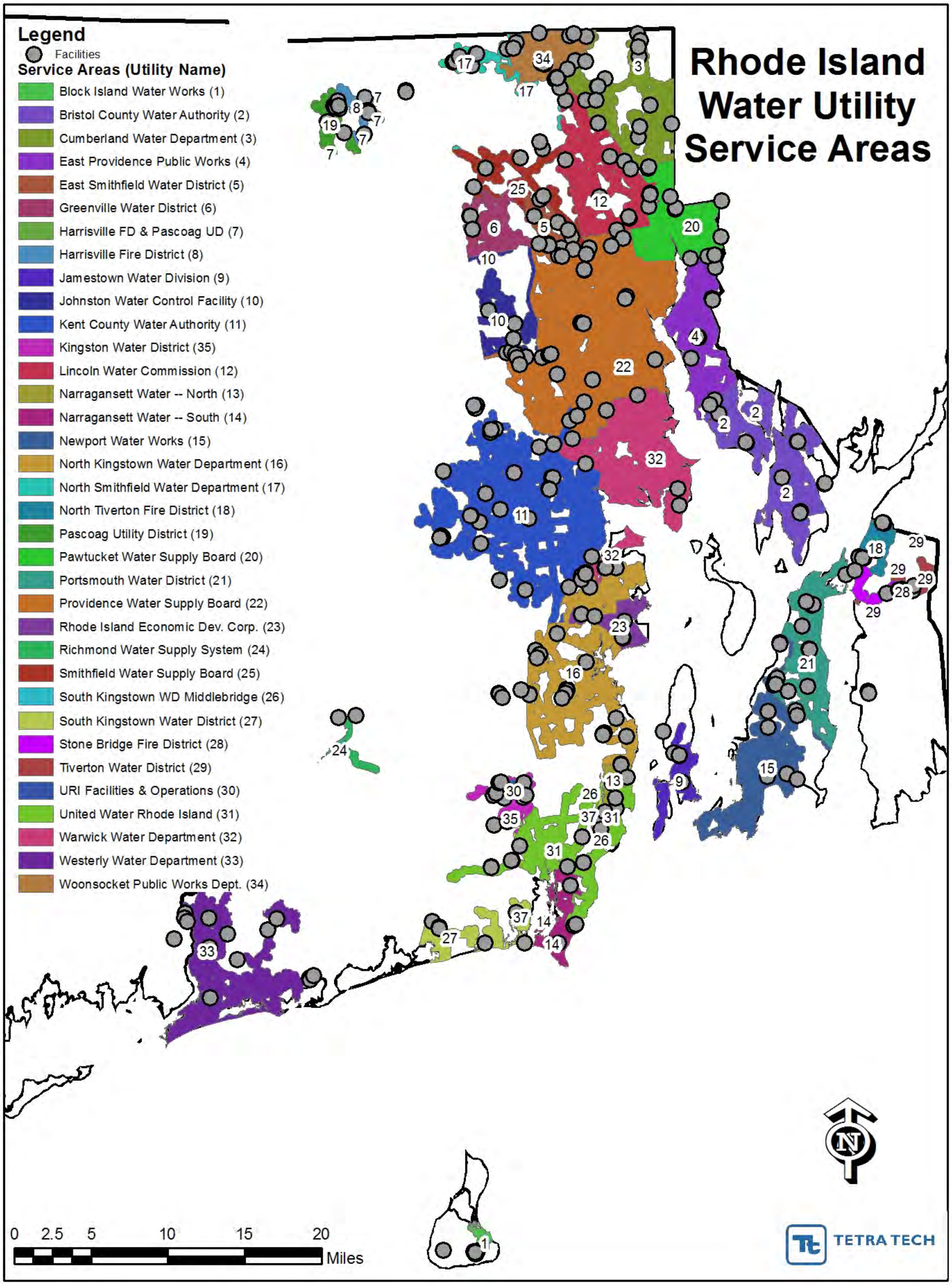

Figure 1. Water utility service and facility map.

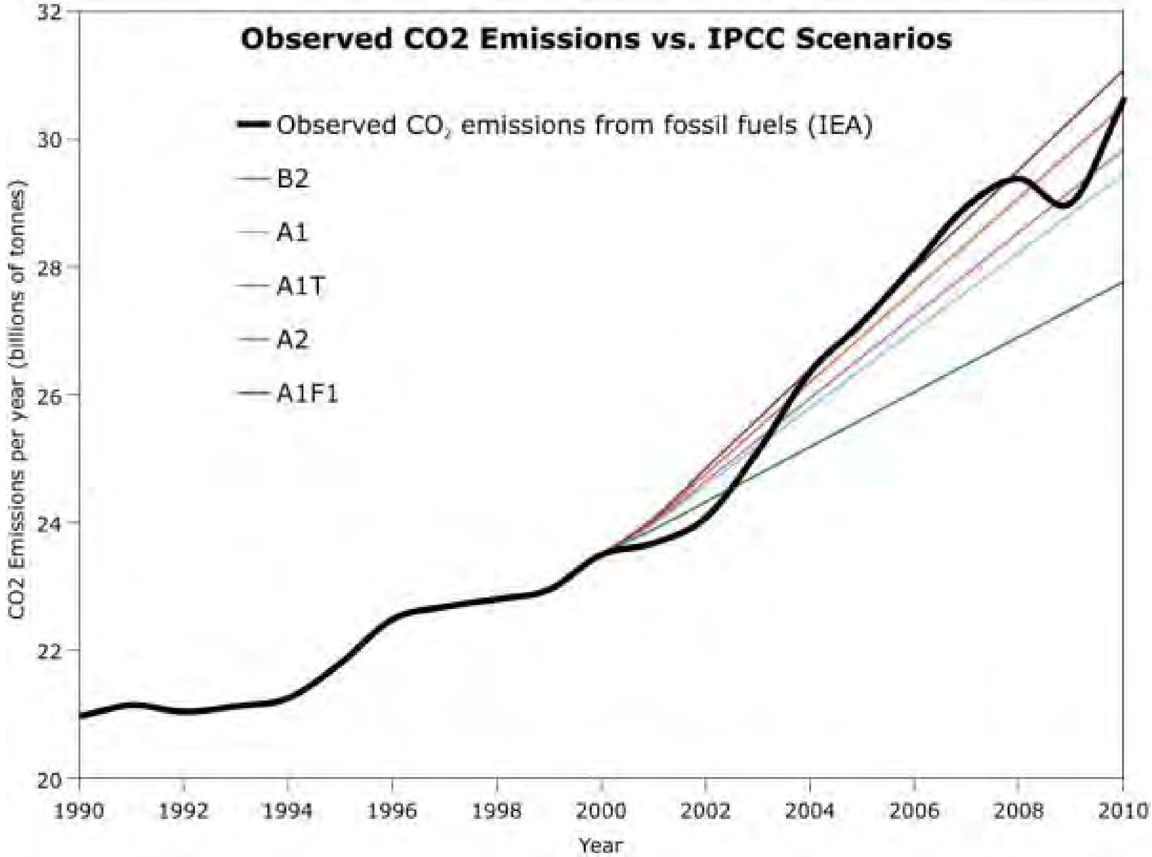

Figure 2. Observed CO2 emissions versus IPCC scenarios

Notes: Data from IPCC emissions scenarios; Data spreadsheet included with International Energy Agency's "CO2 Emissions from Fuel Combustion 2011 - Highlights"; and Supplemental 2010 IEA data; and Supplemental 2011 IEA data. Source: http://www.skepticalscience.com/graphics.php

2.1 Priority Vulnerability Matrix

A priority vulnerability matrix was developed based on the Phase 2 findings to identify those water utilities that are the most vulnerable to climate change impacts, as well as to illustrate the relative susceptibility of each water utility to the hazards assessed in the impact assessment.

For each hazard, the drinking water utility was provided with an intensity score. The intensity matrices below identify the intensity scores, corresponding colors, and descriptions. The drought assessment did not provide similar quantified data as was provided for the other hazards due to the lack of infrastructure impacts; therefore, information from the *Rhode Island Water 2030* was used to provide utility specific drought information where available (RIDP 2012).[3]

[3] The Phase 2 Impact Assessment used HAZUS-MH software to assess direct infrastructure impacts that water utilities would have from riverine and coastal flood inundation, submersion from sea level rise, and from storm surge inundation and wind due to hurricane impacts. Because drought does not directly impact water utility infrastructure, similarly corresponding data was not able to be generated from HAZUS-MH. Instead, a drought hazard analysis was conducted using projected changes in surface water flows in response to future climate for the Pawtuxet River Basin. Refer to the Phase 2 Impact Assessment Report for more information.

2.1.1 Drought Intensity Rankings

The impacts assessment evaluated water supply for the Pawtuxet River Basin at three different time horizons (2022, 2052, and 2084) for two emission scenarios and four Global Circulation Models (GCMs). Although water supply was not modeled for other watersheds and aquifers in the state, the Pawtuxet River Basin supplies water for the Scituate Reservoir. The Scituate Reservoir supplies drinking water to more than 60 percent of the state population, including the city of Providence. Nine of the state's major drinking water utilities depend on the reservoir: Warwick Water Department, Kent County Water Authority, East Providence Water Utility Division, Bristol County Water Authority, Lincoln Water Commission, Greenville Water District, Smithfield Water Supply Board, Johnston Water Department, and East Smithfield Water District.

The climate assessment results predict an increase in the total average annual flow volume relative to the current baseline over each of the three time horizons. However, comparison of the climate change scenarios shows that the seasonal timing of the flow could be of concern for water managers, with some climate scenarios predicting significantly decreased summer flows, particularly for the 2052 and 2082 time horizons. The projected low flows could negatively impact the water supplies of the Scituate Reservoir. In addition, population projections indicate that population increases will increase demand across the state (assuming current use rates) by an average of +0.8 percent (2022), +3.0 percent (2052), and +5.3 percent (2084). Recent reports have highlighted concerns that the Scituate Reservoir will be unable to maintain safe yields based on growing demands, and that "it may actually be physically impossible to guarantee water supply to all land areas now covered by the entitlements granted by state law" (RIDP 2012).

Historically, the summer months are the most critical water usage periods in the state, with some water systems more than doubling their average use (RIDP 2012). The significant increase in use is attributable to growing popularity of outdoor residential water usage in suburban areas, as well as an influx of tourists in some areas (RIDP 2012). To date, the water utilities in Rhode Island have been able to compensate for drought periods by using interconnections to share the water supply and by imposing water restrictions, but with additional demand and a reduced flow, there could be negative impacts.

The Rhode Island Division of Planning (RIDP) evaluated the most recent Water Supply System Management Plans (WSSMPs) to obtain projected water data demand for the 20 year planning period from the largest RI drinking water utilities, including the total volume of consumed water, the available water to the system, and anticipated future demands (RIDP 2012). Based on this information, RIDP developed a detailed comparison of the anticipated demands in relation to available water for the reporting water utilities for the 2030 time horizon. While the RIDP assessment did not consider how climate change will impact hydrology and hence, changing water supply in the state, the assessment provides a useful criteria of water utility drought risk. The drought intensity scores in Table 1 are based on the RIDP data.

It should be noted that the climate change assessment conducted for the *Safe***Water** RI project did not include a groundwater assessment. Several drinking water utilities in the southern portion of the state, including the Westerly Water Department, South Kingstown Water District, Narragansett Water, United Water Rhode Island, and North Kingstown Water District, rely entirely on groundwater supplies. These groundwater supplies are located along the coastline of the state and could be at increased risk from salt water intrusion from sea level rise, coastal flooding, and storm surge. While quantitative data is not available as to the degree of risk that groundwater supplies face from climate change impacts, it is recommended that water utility managers consider that risk in addition to the intensity ranking below.

Table 1. Drought intensity: Priority vulnerability matrix rankings

Intensity Score	Color	Subjective Description
-	-	Information is not available. It is not-known whether utility is at risk.
0		Available water is anticipated to be at or greater than 5 millions of gallons per day (MGD) to meet projected 20-year demand (RIDP 2012). The water utility is not considered to be at risk from drought.
1		Available water is anticipated to be greater than 3 and less than 5 MGD to meet projected 20-year demand (RIDP 2012). The water utility is considered to be at low risk from drought.
2		Available water is anticipated to be greater than 2 and less than 3 MGD to meet projected 20-year demand (RIDP 2012). The water utility is considered to be at low to moderate risk from drought.
3		Available water is anticipated to be less than 2 MGD to meet projected 20-year demand (RIDP 2012). The water utility is considered to be at moderate to severe risk from drought.
4		Available water is not anticipated to meet projected 20-year demand (RIDP 2012).The water utility is considered to be at severe risk from drought.

2.1.2 Other Hazard Rankings

The intensity rankings developed for the other hazards assessed in the *Safe***Water** project, including from sea level rise, coastal flooding, riverine flooding, and hurricanes, are described in Table 2 below.

Table 2. Hazard intensity (sea level rise, coastal flooding, riverine flooding, hurricane): Priority vulnerability matrix rankings

Intensity Score	Color	Subjective Description
0		Water utility has no modeled infrastructure loss from hazard and is not located in an area considered at-risk from the hazard. Based on current data and model outputs, the water utility is not considered to be at risk from the hazard.
1		Water utility has no modeled infrastructure loss from hazard. The water utility is located in proximity to facilities that will experience some losses or in an area considered at some risk from the hazard (e.g., proximity to ocean for coastal flooding). The water utility is considered to be at low risk from the hazard.
2		Water utility has no modeled infrastructure loss from hazard, but is located in proximity to facilities that will experience moderate to severe losses. The water utility is considered to be at low to moderate risk from the hazard.
3		Water utility has modeled infrastructure loss occurring in mid- to late- century (2052 and 2084). The water utility is considered to be at moderate to severe risk from the hazard.
4		Water utility has modeled infrastructure loss occurring in near-term (2022) and/or the at-risk facility has significant infrastructure at risk (e.g., water treatment plant) in mid- to late- century (2052 and 2084). The water utility is considered to be at severe risk from the hazard.

2.1.3 Rhode Island Drinking Water Utility Priority Vulnerability Matrix

The priority risk matrix shows the intensity ranking of each hazard for the water utilities assessed in the Phase 2 impact assessment. The number provided for each utility corresponds to the number assigned to that utility in Figure 1. Further detail on the modeled infrastructure losses can be found in Tables 6-17 in the Impact Assessment Report.

The Warwick Water Department is considered the most vulnerable water utility to the potential impacts of climate change, having received a score of 4 for four hazards (sea level rise, coastal flooding, riverine flooding, and hurricanes) and a score of 3 for drought. The following utilities are considered critically vulnerable to the potential impacts of climate change, having received a score of 4 for three hazards: Bristol County Water Authority, Jamestown Water Division, Newport Water Department, North Kingstown Water Department, Providence Water Supply Board, South Kingstown Water District-Middlebridge, South Kingstown Water District, Stone Bridge Fire District, and United Water Rhode Island.

Table 3. Priority risk matrix

Number	Water Utility	Drought	Sea-level Rise	Coastal Flooding	Riverine Flooding	Hurricane
1	Block Island Water Works	-	3	1	0	1
2	Bristol County Water Authority	0	4	4	0	4
3	Cumberland Water Department	0	0	0	4	0
4	East Providence Public Works	3	4	2	0	2
5	East Smithfield Water District	4	0	0	2	0
6	Greenville Water District	4	0	0	1	0
7	Harrisville Fire District and Pascoag Utility District	3	0	0	3	0
8	Harrisville Fire District Water Department	3	0	0	3	0
9	Jamestown Water Division	3	4	4	0	4
10	Johnston Water Control Facility	3	0	0	2	0
11	Kent County Water Authority	0	3	2	4	1
35	Kingston Water District	2	0	1	3	1
12	Lincoln Water Commission	3	0	0	4	0
13	Narragansett Water Department - North	3	3	2	2	4
14	Narragansett Water Department - South	3	4	4	0	2
15	Newport Water Department	2	4	4	0	4
16	North Kingstown Water Department	2	3	4	4	4
17	North Smithfield Water Department	-	0	0	2	0
18	North Tiverton Fire District	4	2	2	3	2
19	Pascoag Utility District	1	0	0	2	0
20	Pawtucket Water Supply Board	0	4	2	3	2
21	Portsmouth Water District	3	3	4	0	4
22	Providence Water Supply Board	-	4	2	4	4
23	Rhode Island Economic Development Corporation	-	4	2	4	2
24	Richmond Water Supply System	-	0	0	1	0
25	Smithfield Water Supply Board	3	0	0	1	0
26	South Kingstown Water District Middlebridge	3	4	4	2	4

Number	Water Utility	Drought	Sea-level Rise	Coastal Flooding	Riverine Flooding	Hurricane
27	South Kingstown Water District	3	4	4	3	4
28	Stone Bridge Fire District	3	4	4	0	4
29	Tiverton Water District	-	0	2	0	1
30	University of Rhode Island	4	0	0	1	1
31	United Water Rhode Island	-	4	4	0	4
32	Warwick Water Department	3	4	4	4	4
33	Westerly Water Department	2	4	3	2	4
34	Woonsocket Public Works Department	3	0	0	3	0

3.0 ADAPTATION GOALS

This section identifies adaptation goals based on those identified in Rhode Island's drinking water state-guide plan, *Rhode Island Water 2030*. It is anticipated that these goals will be further refined through consultation with HEALTH and the water utilities. These adaptation goals address priority vulnerabilities identified in the Phase 2 impact assessment and presented in Table 3. The following three adaptation goals have been identified for further investigation in Section 4:

1. Prevent infrastructure losses to water utilities from hazards
2. Ensure adequate potable water supplies
3. Use integrated management and planning to increase adaptive capacity

The sections below will elaborate on these goals and will also detail any relevant planning or regulatory efforts that have been developed to help water utility managers meet the goals so that this report will build off of ongoing efforts.

3.1 Adaptation Goal #1: Prevent Infrastructure Losses to Water Utilities from Hazards

The Phase 2 modeled results show that all of the major water utilities in Rhode Island are at some degree of risk to one or more of the hazards assessed in the *Safe***Water** project, including from sea level rise, coastal flooding, riverine flooding, and hurricanes (wind and storm surge). Specific infrastructure losses that the water utilities could experience in the three time horizons (2022, 2052, and 2082) were identified through the impact assessment. This adaptation goal recognizes that water utilities, particularly those whose infrastructure could be impacted from hazards in the near-term, should develop adaptation strategies to prevent or minimize infrastructure losses.

Rhode Island is one of only two states in the United States that has specific laws or regulations that require planners to consider sea level rise in land use planning (the other state is Massachusetts).[4] Relevant laws or regulations include the following:

Laws/Regulations

- The Rhode Island Legislature passed a law in 2006 to amend the state building code, explicitly addressing sea level rise and climate change (R.I.G.L. §23-27.3-100.1.5.5)

[4] For more information see: <http://www.cga.ct.gov/2012/rpt/2012-R-0418.htm>.

- Pursuant to R.I.G.L. § 23-27.3, Rhode Island's Building Code Commission amended the building code to consider the impacts of sea-level rise when developing new regulations and required all new development in certain coastal zones to be built one foot above base flood elevation.
- The Rhode Island Legislature amended the Comprehensive Planning Act (§ 45-22.2-8) in 2011 to require that municipalities consider natural hazards, such as flooding and sea-level rise. Municipalities have until June 2016 to bring their comprehensive plans into conformance.[5]

Policies/Procedures

- Rhode Island's Coastal Resource Management Council (CRMC) is responsible for coordinating the state's response to sea level rise. The Council has adopted regulations under which it will review its policies, plans, and regulations to plan for and adapt to climate change and sea-level rise (Rhode Island Coastal Resources Management Program § 145). The Council's policy is to accommodate a base rate of a 3 to 5 foot rise in sea level by 2100 in the siting, design, and implementation of public and private coastal activities and to ensure proactive stewardship of coastal ecosystems under these changing conditions.[6]

3.2 Adaptation Goal #2: Ensure Adequate Potable Water Supplies

Although drought is not currently impacting most water utilities, the modeling for this study indicates that drought and precipitation variability (or decreases in precipitation shown for some models), combined with competing water uses, may negatively impact water available in the future. Specifically, the projected low flows during the summer months could negatively impact the water supplies of the Scituate Reservoir.

Additionally, water utilities in the southern region of Rhode Island rely solely on groundwater, and have no additional storage. Salt water intrusion from sea level rise, coastal flooding and storm surge could negatively impact groundwater supplies in the future. Ensuring adequate potable supplies of water for the state will require considering the potential impact that climate change could have on Rhode Island groundwater basins and the resultant impacts on groundwater safe yields.[7]

Several Rhode Island government agencies, including HEALTH, the Water Resources Board (RIWRB), and the Division of Planning have taken measures to assess the state's vulnerability to drought and to address the issue. Those measures considered most pertinent to identifying and developing adaptation strategies for this report are listed below:[8]

Laws/Regulations

- Water Use and Efficiency Act [Rhode Island General Law (R.I.G.L.) § 5828, 2009, Chapter 15.1]. The purposes of the Act include managing demand for potable water and reinvesting in water supply infrastructure. Under the Act, major water suppliers are required to take effective action to reduce the waste of water, and are encouraged to consider conservation pricing, and major water suppliers are required to maintain reserve funds adequate for infrastructure maintenance and to stabilize revenue losses from demand management programs.

[5] For more information see: <http://www.planning.ri.gov/comp/rrilocat_2012.pdf>.
[6] For more information see: <http://www.crmc.ri.gov/regulations_adopted/2008-03-04_RICRMP_Section_145.pdf>.
[7] Safe yield is defined "as a sustainable withdrawal that can be continuously supplied from a water source without adverse effects throughout a critical dry period with a one percent change of occurrence, or one that is equivalent to the drought of record, whichever is worse." Rhode Island General Law (46-15.7-2).
[8] This list is by no means comprehensive. See the Water Resource Board site for additional information: http://www.wrb.state.ri.us/lawsregs.htm.

- Rules and Procedures for Water Supply System Management Planning (WSSMP), Drought Management Component (Section 8.09).[9] WSSMPs are prepared by water suppliers that produce over fifty million gallons of water per year. The drought management component requires that water utilities: address emergency circumstances and restoring water as quickly as possible; manage the system in preparation for and during drought; coordinate the status of written agreements with other water systems, particularly emergency interconnection agreements; define drought indices and establish demand reduction actions for their system; and set demand reduction goals for each stage of drought.

Policies/Procedures

- The *Rhode Island Drought Management Plan* was developed by RIWRB to provide the state with a policy guide and framework for coordinated responses in times of long-term drought (RIWRB 2002).
- RIWRB commissioned *a Statewide Supplemental Water Supplies Feasibility Assessment* (2008) for major public water supplies throughout the state to identify and evaluate the risks to the major public water suppliers of a catastrophic failure that would result in the need of a supplemental water supply and to determine the quantity of water required from the supplemental or alternate water source.
- RIDP developed *Rhode Island Water 2030,* which identifies goals and actions deemed essential to maintain existing water supplies and to protect future ones.

3.3 Adaptation Goal #3: Promote Integrated Watershed Management and Planning for Increased Resilience

Watershed-scale planning and management uses watershed boundaries to organize planning efforts, allowing for a holistic approach to water management. This provides the context for understanding local natural constraints and opportunities, and the key local drivers for increased resilience. It also provides the context for establishing specific environmental performance objectives and cross-sector initiatives (EPRI 2009). Building institutional capacity is a fundamental enabling component toward more sustainable water resource management. Planning and capacity building strategies that promote integrated water resources management could provide cost-effective methods for building resilience to longer term climate change.

There are a variety of programs that promote integrated watershed management and capacity building for water utilities. The Rhode Island Department of Environmental Management (DEM) developed the RI Watershed Approach, which is a strategy for comprehensive, community-based management of the state's environment (DEM 1999). DEM has incorporated the RI Watershed Approach into its annual workplan, which coordinates the agency's activities and specifies its goals and objectives.[10]

HEALTH and the Rhode Island Clean Water Finance Agency codirect the *Public Water System Supervision Program* and annual capitalization grant as part of the revolving loan fund from the U.S. Environmental Protection Agency (EPA). Part of the program consists of providing technical assistance to managers and operators of public water systems.

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[9] Pursuant to Chapter 46-15.3 of the Rhode Island General Laws (1997).
[10] For a synopsis of the RI Watershed Plan, see:
<http://www.gso.uri.edu/maritimes/Back_Issues/99Fall/Text%20(htm)/ribb_ardito.htm>.

4.0 ADAPTATION STRATEGIES

The three major subsections in this section present and provide evaluations of adaptation strategies for the three adaptation goals identified in Section 3. Several strategies are initially proposed for each goal, because concurrent implementation of several strategies in coordination with each other often helps assure the adaptation goal is met, and because the screening process implemented for each adaptation strategy in this section is anticipated to remove some strategies from further consideration.

Each adaptation strategy is screened using a number of feasibility criteria – social, technical, administrative, political, legal, economic, and environmental (STAPLEE). STAPLEE criteria are used to evaluate potential hazard mitigation options in the U.S. Federal Emergency Management Agency (FEMA) and they provide general evaluation categories that will serve this analysis. This evaluation supported the ranking of the strategies and helps to determine each strategy's feasibility. The criteria are structured for this study's screening effort as follows:

- **S**ocial: Adaptation strategies are acceptable to water utilities and customers if they do not adversely affect a particular segment of the population; do not cause relocation of disadvantaged people; and if they are compatible with social and cultural values.
- **T**echnical: Adaptation strategies are most effective if they are technically feasible; provide long-term reduction of losses; and have minimal secondary adverse impacts.
- **A**dministrative: Adaptation strategies are administratively easier to implement if water utilities have the necessary staffing and funding, and can provide the necessary maintenance requirements.
- **P**olitical: Adaptation strategies can be politically successful if all stakeholders have been offered an opportunity to participate in the planning process and if there is sufficient political and public support for the strategy.
- **L**egal: For proper implementation and enforcement of an adaptation strategy, it is critical that implementing and enforcement agencies are in place, have the legal authority to act, and support the strategy.
- **E**conomic: Budget constraints can significantly deter the implementation of adaptation strategies, therefore it is important to evaluate whether the strategy is cost-effective, if there are available funding sources, and if the strategy contributes to other economic goals.
- **E**nvironmental: Sustainable adaptation strategies do not have an adverse effect on the environment, comply with state and federal regulations, are consistent with the state's environmental goals, and have benefits while being environmentally sound.

An evaluation rating system was developed and is presented in Table 4.

Table 4. Adaptation strategy ranking framework

Evaluation Criterion and Ratings			
Significantly Adverse (SA)	Insignificant (I)	Significantly Beneficial (SB)	Unknown (U)
Social			
Strategy is not acceptable to the customers because it may adversely affect a particular segment of the population; or there is potential to cause relocation of disadvantaged people; or it is not compatible with social and cultural values.	Strategy is not expected to result in significant effects on social or cultural values.	Strategy is acceptable to the customers because it significantly benefits the customer community as a whole; and promotes the local social and cultural values.	The effects of the strategy on social and cultural values are unknown.

Technical			
Strategy is not technically feasible; or does not provide long-term benefits; or has adverse secondary impacts.	Strategy is not expected to result in significant effects on technical issues.	Strategy is easy to implement, provides long-term benefits, and has no adverse secondary impacts.	The technical feasibility and/or the potential for secondary adverse impacts of the strategy are unknown.
Administrative			
Staffing and/or funding will be insufficient; or maintenance *requirements* will be beyond the utility's capabilities; such that it jeopardizes the success of the strategy.	Strategy is not expected to result in significant effects on administrative issues.	There is sufficient staffing, funding, and maintenance capabilities to meet the requirements for the strategy to be successful.	The effects of the strategy on administrative issues are unknown.
Political			
Most customers are strongly opposed to the proposed strategy or there may be significant political opposition to the strategy.	Strategy is not expected to result in significant effects on political issues.	Most customers strongly support the strategy.	The effects of the strategy on political issues are unknown.
Legal			
Proper implementation and enforcement of the proposed strategy is jeopardized due to a lack of jurisdiction or legal authority to do so.	Strategy is not expected to result in significant effects on legal issues.	Sufficient jurisdiction and/or legal authorities exist such that proper implementation and enforcement of the proposed strategy is likely to be successful.	The effects of the strategy on legal issues are unknown.
Economic			
Budget constraints will significantly deter the implementation of the strategy. Strategy cost outweighs the benefits.	Strategy is not expected to result in significant effects on economic issues.	Strategy is significantly cost effective; or will result in significant economic benefit for the utility.	The effects of the strategy on economic issues are unknown.
Environmental			
The strategy has an adverse effect on the environment; or does not promote environmental sustainability; or does not comply with environmental regulations; or is not consistent with the country's environmental goals.	Strategy is not expected to result in significant effects on environmental issues.	Strategy may have a beneficial effect on the environment, promotes environmental sustainability, complies with environmental regulations, and is consistent with the state's environmental goals.	The effects of the strategy on environmental issues are unknown.

The ratings for each adaptation strategy were then assigned a weighting, as follows: (1) SB = 1; (2) I = 0; (3) SA = -1. Ratings of "U" were not assigned a numerical weighting. As such, they do not have any effect of the overall score of each strategy; however they do show a deficiency in data that, when resolved, may affect the overall priority of the adaptation strategy. Therefore the results of these ratings should only be viewed as preliminary data and should not be applied to long-term planning efforts until new data have allowed the "U" ratings to be replaced by one of the other STAPLEE ratings. Input from the water utilities, HEALTH, and appropriate stake holders is recommended to address the unknown category, as well as to identify/confirm the most appropriate strategies.

The following subsections present, and provide evaluations of, adaptation strategies for each of the three adaptation goals identified in Section 4.

4.1 Adaptation Goal #1: Prevent Infrastructure Losses to Water Utilities from Hazards

The impact assessment conducted in Phase 2 of the *Safe***Water** RI project identified several utilities that are currently at-risk to sea level rise, coastal and riverine flooding, and/or hurricanes, or are projected to be at risk in a future time-period. The quantified impacts of total infrastructure losses are summarized in Table 5 below (refer to Phase 2 Impacts Assessment Report for a full breakdown of losses). The losses included in Table 5 are for infrastructure only and do not address lost revenue due to reduced water service capabilities. Two strategies are identified in this section that could help prevent losses to drinking water utilities.

Table 5. Total infrastructure losses per hazard (Phase 2 Impacts Assessment Report)

Hazard	Number of Impacted Utilities	Number and Types of Impacted Infrastructure (5 ft scenario or 2084)	Total losses (5 ft scenario or 2084)
Sea Level Rise	35	• 507,830 feet Pipelines (5 ft scenario) • 4 Booster Pump Stations • 3 Interconnections	$87,491,975
Coastal Flooding	11	• 5 Booster Pump Stations • 9 Interconnections • 2 Treatment Plants • 3 Wells	$22,710,000
Riverine Flooding	13	• 9 Booster Pump Stations • 6 Interconnections • 1 Reservoir • 7 Wells	$4,070,000
Hurricane	13	• 10 Booster Pump Stations • 10 Interconnections • 1 Pretreatment Facility • 3 Treatment Plants • 3 Wells	$34,451,000

4.1.1 Strategy 1: Retrofit/relocate at-risk infrastructure

Under this strategy, water utilities would evaluate the modeled at-risk infrastructure for their utility and anticipated time horizon for impact, and determine whether the infrastructure could be retrofitted to withstand the impact or whether the infrastructure would need to be rebuilt in a different location outside of the hazard area. The average value of the at-risk infrastructure is presented in Table 6.

Table 6. Average total value of infrastructure

Type of Infrastructure	Average Total Value
Booster Pump Station	$200,000
Interconnection	$1,000,000
Pipeline	$50,000
Pretreatment Facility	$5,000,000
Storage Tank	n/a
Treatment Plant	$15,000,000
Well	$1,000,000

For both total value and potential system impact, the most critical at-risk infrastructure are the three treatment plants, owned by the Newport Water Works, Jamestown Water Division, and Bristol County Water Authority. From coastal flooding, the Newport Water Works treatment plant (total value estimated at $10 million) is projected to be subject to 8 foot flooding by 2022, with losses estimated at $3 million, and from a 5-foot sea level rise could be subject to 15 foot flooding, with losses estimated at $4 million. The Newport Water Works treatment plant is also at-risk to hurricane impacts from wind and storm surge, with losses projected at over $3 million for the 2022 timeframe and over $6 million with a 5-foot sea level rise. The impacts are thus projected to be over half of the total value of the water treatment plant. According to the RIWRB *Statewide Supplemental Water Feasibility Assessment* (2008) the water treatment plant is not considered the most critical water source supply for the utility; however, the facility is an important component of Newport Water Works water portfolio.

Jamestown Water Division has a treatment plant (total value estimated at $30 million) at-risk from both coastal flooding and hurricane impacts. The treatment plant is projected to be subject to approximately 6 foot flooding by 2022, with losses estimated at $4 million, and from a 5-foot sea level rise could be subject to 10 foot flooding, with losses estimated at $12 million. Hurricane damages are projected at $7 million for the 2022 timeframe and $18 million with a 5-foot sea level rise. Thus, the total damages could be almost half of the value of the water treatment plant. Critically, the RIWRB Feasibility Assessment identified the Jamestown Water Treatment Facility as the most vulnerable water source of the utility. According to the assessment; "in order for potable water from the reservoirs to reach the Jamestown customers it must first be treated at the WTP…a failure of either one of these components [the North Pond Reservoir and the Jamestown Water Treatment Facility] would affect the Jamestown system greatly" (RIWRB 2008).

The Bristol County Water Authority treatment plant (total value estimated at $5 million) is vulnerable to hurricane impacts (e.g. wind and storm surge). Damages from hurricanes are projected at $1.5 million for the 2022 time horizon and $3 million from a 5-foot sea level rise. The total damages are over half the value of the treatment plant. The RIWRB Feasibility Assessment determined that the Bristol County Water Authority could obtain emergency water through regional sources (RIWRB 2008); however, it is not clear what the impact from the loss of the water treatment plant would pose to Bristol County customers.

Due to the time-horizon of projected impacts (2022, with increasing risk moving forward), as well as the projected flood depths (6 feet to 15 feet), it is recommended that these three water utilities consider relocating the at-risk infrastructure, or at the least, have long-term measures in place to compensate for potential system impact. It may be appropriate for these utilities to consider the alternative water supply sources identified in Adaptation Goal #2, Strategy 1.

Under this strategy, water utilities would evaluate their at-risk infrastructure to determine the potential system impact. Alternatives and plans for retrofitting, relocating, or abandoning non-critical elements, could be considered in the respective WSSMPs in a 5-year or 20-year time-frame. When considering retrofitting as an option, water utilities could take the following measures:

- Install underground water pumps at critical points.
- Raise or strengthen infrastructure to withstand flooding.
- Install floating or flexible infrastructure, such as flexible pipes. This technology has not been widely demonstrated in high-density cities.
- Work with state and municipal governments to develop linear protection, such as levees and seawalls.

Consideration of the projected flood depth would be important to ensuring that the retrofitted infrastructure could withstand the impact.

Implementation of this adaptation strategy, particularly for those water utilities with critically at-risk infrastructure, would have significantly beneficial social impacts. Under this strategy, water utilities would put in place measures to protect water utility customers from disruptions in water service during natural disasters and from long-term projected changes in sea level rise. It is not anticipated that there would be technical, legal, or political adverse impacts to this alternative. Development of linear protection could have adverse environmental impacts, which would need to be further explored in environmental impact assessments. Economic and administrative constraints of the water utility would pose the greatest obstacle to implementing this strategy.

4.1.2 Strategy 2: Use of *Safe*Water RI tools for new infrastructure siting

The Phase 2 impacts assessment used the Federal Emergency Management Agency's (FEMA's) HAZUS-MH software[11] to evaluate climate change hazards posed to water utilities' infrastructure from riverine and coastal flooding, sea level rise, and hurricanes. HAZUS-MH is an established public-domain simulation model. A FEMA training is currently being planned by FEMA, Tetra Tech, and the University of Rhode Island to enable water utility representatives to learn how to use this free modeling software, at no-cost to the utility (except for staff time to attend the training). Under this strategy, water utility representatives would participate in the training to enable continued analysis by the water utilities as new data becomes available and to run new scenarios for new infrastructure siting. Alternatively, water utility managers could evaluate the GIS data developed in the *Safe***Water** RI project to determine if proposed infrastructure would be at risk.

This adaptation strategy is considered low-cost and is not anticipated to have adverse implications to the STAPLEE areas. This strategy could have beneficial social impacts due to the potential for minimizing disruptions in water service to customers during natural disasters and from long-term projected changes in sea level rise. There could be administrative constraints related to implementing this adaptation strategy if personnel are unable to attend the training or use the *Safe***Water** RI GIS data.

4.1.3 Adaptation Goal #1 Strategy Evaluation

The two adaptation strategies in this section were assessed according to the STAPLEE criteria (refer to Table 4: Adaptation Strategy Ranking Framework) and results are presented in Table 7. Given that the technical, administrative, and economic capabilities of the state's water utilities vary, sometimes considerably, there are several "U's" (e.g. the effects of the strategy on those issues are unknown) for those areas. It is recommended that each water utility further consider the applicability of the STAPLEE rankings relative to their utility, to determine the priority adaptation strategies that could assist their utility in meeting adaptation goal #1.

Table 7. Adaptation Goal #1 strategy evaluation

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
1. Retrofit/relocate at-risk infrastructure (P, O)	+1	0	U	0	+1	U	U	+2
2. Use of *Safe*Water RI tools for new infrastructure siting (P, O)	+1	+1	U	0	+1	+1	+1	+5

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: Significantly Adverse = -1; Insignificant= 0; Significantly Beneficial= +1; Unknown= U.

[11] For more information see: <http://www.fema.gov/hazus>.

The results indicate that both adaptation strategies could provide overall beneficial impacts, and that the use of *Safe***Water** RI tools for new infrastructure siting could be a particularly low-cost option to ensure that new infrastructure is not sited in at-risk areas.

4.2 Adaptation Goal #2: Ensure Adequate Potable Water Supplies

The risk assessment has identified drought and precipitation variability as a major concern for water utilities, particularly in the summer months. Several strategies are identified in this section that could help prevent losses to drinking water utilities. Some of these strategies may be undertaken by water utilities directly and others would require a more coordinated effort with other government agencies.

It is difficult to quantify the benefits of the adaptation strategies below, since records do not indicate any specific instances where water utilities have incurred losses due to low water supply in the Scituate Reservoir; it appears it has managed operations during low storage periods. As noted earlier however; concerns have been raised about the ability of the Scituate Reservoir to meet projected future demand, even without taking into account the projected decrease in precipitation during summer months by several climate scenarios evaluated in the impact assessment. In addition, several utilities rely entirely on groundwater supplies that could be impacted by salt water intrusion from sea level rise or coastal flooding, and have no additional storage. While there are currently no withdrawal limits on groundwater supplies, the RIWRB is currently conducting an assessment of safe and sustainable withdrawal rates (from Phase 1 Report). If withdrawal limits are developed based on the assessment findings, then several water utilities would have to address potential shortages.

4.2.1 Strategy 1: Implement Local Proposed Alternative Water Supply Sources

The RIWRB *Statewide Supplemental Water Supplies Feasibility Assessment* (2008) evaluated the critical water sources for the state's major water utilities and identified local proposed alternative water supply sources for each utility. Under this strategy, water utilities would evaluate the local proposed alternative water supply sources proposed for their utility as a way to build resilience into their systems in the case of drought. The alternatives are included in Table 8 below.

Table 8. Local proposed alternative water supply sources for each utility (RIWRB 2008)

Drinking Water Utility	Proposed Alternative Water Supply Sources	Projected Cost
Block Island Water Company	None identified; supply capacity considered sufficient	n/a
Cumberland Water District	None identified; supply capacity considered sufficient	n/a
Harrisville Fire District	New well field development	$1,388,400
	North Smithfield to Harrisville interconnection	$7,667,026
Jamestown Water Division	Enhance connection with North Kingstown	n/a
Kent County Water Authority	New Wellfield reservoir at Big River	See regional solution
Kingston Water District	None identified; supply capacity considered sufficient	n/a
Narragansett Water Department	None identified; supply capacity considered sufficient	n/a
Newport Water Division	*Connection to Fall River, MA**	$2,651,220
North Kingstown Water Department	None identified; supply capacity considered sufficient	n/a
North Smithfield Water Department	New Tifft Road Well	$546,000
	Interconnection with Harrisville	$7,667,026
North Tiverton Fire District	*Connection to Fall River, MA**	$2,651,220
Pascoag Utility District	*New groundwater sources**	$733,200

Drinking Water Utility	Proposed Alternative Water Supply Sources	Projected Cost
Pawtucket Water Supply Board	Providence Water Supply Board (PWSB) to Pawtucket Interconnection A	$9,620,000
	PWSB to Pawtucket Interconnection B	$6,890,000 (plus pumping station)
Portsmouth Water and Fire District	*Connection to Fall River, MA**	$2,651,220
Richmond Water Supply District	None identified; supply capacity considered sufficient	n/a
South Kingstown Water Department	None identified; supply capacity considered sufficient	n/a
Stone Bridge Fire District	*Connection to Fall River, MA**	$2,651,220
United Water of Rhode Island	None identified; supply capacity considered sufficient	n/a
University of Rhode Island Facilities and Operations	None identified; supply capacity considered sufficient	n/a
Westerly Water Division	None identified; supply capacity considered sufficient	n/a
Woonsocket Water Department	Rehabilitation of existing interconnection with Lincoln	$2,652,000
	Interconnection with Cumberland	$638,040

*Note: The italicized alternative water supply sources are currently in progress.

The projected costs of implementing the proposed alternatives are identified in Table 8 and vary from no cost (e.g., no alternative was identified because water supply capacity was considered sufficient) upwards to $40 million. All of the alternatives identified in Table 8 are considered technically feasible given the RIWRB assessment. Although the environmental impacts of the specific alternatives would need to be further evaluated, there is a low likelihood that significant adverse impacts would result from the alternatives. It is also anticipated that there would be minimal social, political, or legal impacts from the implementation of these alternatives. There may be administrative and economic barriers to implement the alternatives due to the personnel and financial constraints of individual water utilities.

4.2.2 Strategy 2: Implement Regional Solutions

Regional solutions to increase the capacity of Rhode Island's drinking water utilities were also evaluated in the RIWRB *Statewide Supplemental Water Supplies Feasibility Assessment* (2008). These regional supplemental emergency water supply sources are considered feasible alternatives to minimize the risk of future drought and dependence on the Scituate Reservoir. Under this strategy, the impacted water utilities and other relevant government agencies such as HEALTH, RIWRB, and DEM would need to coordinate to implement the regional solutions to increase available water supply sources. The alternatives are included in Table 9 below.

Table 9. Regional supplemental emergency water supply sources (RIWRB 2008)

Regional Supplemental Emergency Water Supply Sources	Utilities Benefited	Identified Requirements or Issues	Projected Construction Cost*
Surplus Water from Fall River	Newport Water Division, North Tiverton Fire District, Portsmouth Water and Fire District, and Stone Bridge Fire District	• Solution is in use but there are issues with the water pressure • Modifications to interconnection contract limitations • HEALTH approval for connections between distribution systems • Water quality must be boosted	$6,399,822

Regional Supplemental Emergency Water Supply Sources	Utilities Benefited	Identified Requirements or Issues	Projected Construction Cost*
Surplus Water from Pawtucket and Woonsocket	Kent County Water Authority and Quonset Development Corporation	• New or upgraded interconnections	$19,918,978
Rehabilitation of Inactive Wells	Providence Water Supply Board	• Water quality issues which will require various levels of treatment • Water supply issues which will require withdrawal management	$132,935,024 (for 5 wells)
Big River Well Field	Kent County Water Authority and Quonset Development Corporation	• Environmental and sustainability concerns (to determine production capacity) • Under review by HEALTH	$26,699,400
Roger Williams Park, Well Development	Providence Water Supply Board	• The groundwater classification, as referenced in the Groundwater Division of the RIDEM, is GB • HEALTH considers this a high risk location	$17,067,648
Reverse Osmosis Desalination *Note: this solution is currently in use in North Kingstown*	TBD. Locations evaluated at East Bay, West Bay and Aquidneck Island	• Detailed environmental and social assessments • Siting, permits	$194,421,000

*Note: The costs included in the table are those for projected construction only and do not include costs associated with operations, maintenance, or water conveyance

The projected costs of implementing the proposed regional alternatives are significantly higher than implementing the local proposed alternative water supply sources, which creates administrative and economic barriers for implementation.[12] There are potentially adverse environmental impacts associated with several alternatives, particularly rehabilitating inactive wells, and alternatives could require detailed environmental assessments. The technical feasibility of several alternatives is thus unclear, or could be considered adverse, depending on the outcomes of the environmental assessments. It is also anticipated that there could be social, political, or legal impacts to the implementation of these alternatives if the costs necessary to implement the alternative place an undue burden on the water utilities' customers and stakeholders, particularly if increased costs negatively impact poor, disadvantaged, or minority populations. Due to these issues, the RIWRB Feasibility Assessment concluded that implementing the local supplemental sources (e.g., strategy 1) is the most feasible. However, should significant decreases in precipitation during summer months begin to adversely impact water utilities, the regional solutions could become more socially and economically feasible.

[12] Though the projected costs of implementing the proposed regional alternatives are significantly higher than implementing the local proposed alternative water supply sources, without further data, individual costs to utilities based on a regional approach cannot be assessed.

4.2.3 Strategy 3: Evaluate Opportunities for Water Reuse

As defined by the EPA, water reuse means using treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (e.g., ground water recharge) (EPA 2012a). The most common type of recycled water is water that has been reclaimed from municipal wastewater. Water reuse can be grouped into the following categories (EPA 1992):

- Urban Reuse: the irrigation of public parks, school yards, highway medians, and residential landscapes, as well for fire protection and toilet flushing in commercial and industrial buildings.
- Agricultural Reuse: irrigation of nonfood crops, such as fodder and fiber, commercial nurseries, and pasture. Note: high-quality reclaimed water can be used to irrigate food crops.
- Indirect Potable Reuse: to supplement recreational impoundments, such as ponds and lakes; for environmental reuse, such as creating artificial wetlands, enhancing natural wetlands, and sustaining stream flows; and for industrial reuse, including process or makeup water and cooling tower water.

There are various levels of water quality treatment that must be met dependent on the water reuse category that is intended. Table 10 identifies the requirements developed by the EPA in *Guidelines for Water Reuse* (1992).

Table 10. Types of water reuse and EPA requirements

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distances
Urban Reuse	Secondary Filtration Disinfection	pH = 6–9 < 10 mg/L biochemical oxygen demand (BOD) <2 turbidity units (NTU) No detectable fecal coliform/100 mL4 1 mg/L chlorine (Cl 2) residual (min.)	• pH: weekly • BOD: weekly • Turbidity: continuous • Coliform: daily • Cl 2 residual: continuous	50 ft (15 m) to potable water supply wells
Agricultural Reuse (Non-Food Crops)	Secondary Disinfection	pH = 6–9 <30 mg/L BOD <30 mg/L total suspended solids (TSS) <200 fecal coliform/100 mL5 1 mg/L Cl 2 residual (min.)	• pH: weekly • BOD: weekly • TSS: daily • Coliform: daily • Cl 2 residual: continuous	300 feet (90 m) to potable water supply wells
Indirect Potable Reuse	Site specific Secondary and disinfection (min.) May also need filtration and/or advanced wastewater treatment	Site specific Meet drinking water standards after percolation through vadose zone.	• pH: daily • Turbidity: continuous • Coliform: daily • Cl 2 residual: continuous • Drinking water standards: quarterly • Other: depends on constituent	100 ft (30 m) to areas accessible to the public (if spray irrigation) site specific

In addition to EPA requirements, DEM has established specific guidelines for the reuse of treated wastewater for landscape irrigation, non-contact cooling water, and irrigation of non-food crops.[13] To date, regulations and standards have not yet been developed for Rhode Island to support expansion of water reuse for other purposes (RIDP 2012). DEM and HEALTH would need to establish those standards in collaboration with other relevant agencies.

Under this strategy, drinking water utilities would collaborate with local wastewater utilities to identify whether, and what type of, water reuse options would be available to supplement water supply. The type of water reuse would need to be considered based on the most pressing water supply need (e.g., summer landscape watering, projected increased in industrial water or agricultural water demand), alongside the required infrastructure and treatment. No detailed studies have been completed to date on the costs required for Rhode Island water utilities to implement water reuse strategies; however, the technical feasibility of water reuse is well-established and water reuse has been successfully implemented in many parts of the country (EPA 2012). DEM has identified eight wastewater treatment facilities with "cluster" opportunities for water reuse: East Greenwich, Narragansett Bay Commission, Quonset, South Kingstown, West Warwick, Westerly, and Woonsocket (RIDP 2012).

Costs of water reuse for potable and non-potable applications vary widely because they depend on site-specific factors, although water reuse projects tend to be more expensive than most water conservation options and less expensive than seawater desalination and other new supply alternatives. According to Dr. Takashi Asano, University of California at Davis (quoted in McKenzie 2004):

> "Recent experience in California indicates that approximately four million U.S. dollars in capital cost are required for each one million m3 per year of reclaimed water that is made available for reuse. Assuming a facility life of 20 years and a nine percent interest rate, the amortized cost of this reclaimed water is about $0.45/m3, excluding operations and management costs."

While there are no documented cases of human health problems due to contact with recycled water that has been treated to standards, criteria, and regulations (EPA 2012), the largest barriers to implementing water reuse strategies are often public misconceptions and fears related to public health and water quality. There have been several instances, such as in California and Texas, where planned water reuse strategies have been derailed due to these concerns (EPA 2012).

4.2.4 Strategy 4: Develop Emergency Water Agreements

The development of emergency water agreements could assist water utilities that are anticipated to have water deficits to obtain water from utilities that have surplus water. For example, the Portsmouth Water and Fire District has an established agreement and an emergency interconnection to obtain water on an emergency basis from the Lawton Valley Water Treatment Plant. Establishing the contractual mechanisms and infrastructure for water utilities to cooperate is a low-cost way to distribute water from surplus areas to those areas that are in need, or projected to be in need. There are no anticipated adverse impacts under this strategy related to social, political, administrative, technical, environmental issues. There could be minimal administrative issues related to greater cooperation between utilities; however, these are not considered adverse or an obstacle to moving forward with this strategy.

The primary constraint to implementing an effective water agreement is proximity to a water utility that has surplus water. Specifically, the southern portion of the state relies entirely on groundwater and is currently more susceptible to drought than the northern portion of the state; most of the southern water utilities are not in proximity to those utilities with surplus water.

[13] For more information see: http://www.dem.ri.gov/programs/benviron/water/permits/wtf/pdfs/reusegyd.pdf.

4.2.5 Strategy 5: Enhanced Operations and Systems Management for Water Efficiencies

Improving water efficiency refers to using improved technologies and practices that deliver equal or better service with less water (EPA 2012b). Under this strategy, drinking water utilities would enhance operations and system management for increased water efficiencies. Improving water efficiency reduces operating costs (e.g., pumping and treatment) and reduces the need to develop new water supplies.

All of the major drinking water utilities in Rhode Island have various strategies and techniques in place to manage their current water quality, water availability, and infrastructure needs. Based on the Phase 1 survey responses, these approaches include: leak detection and notification programs; maintenance, repair, and replacement of aging infrastructure; meter upgrades; and cleaning and lining of pipes. Under this strategy, water utilities would evaluate the strategies and programs that are currently in place, and identify additional measures that could improve water efficiency. EPA identifies three primary techniques that water utilities can use to enhance operations and systems management to increase water efficiencies (EPA 2012b):

- Water metering: When water systems meter use by their customers. Metering helps to identify losses due to leakage and also provides the foundation on which to build an equitable rate structure to ensure adequate revenue to operate the system.
- Water loss control: National studies indicate that, on average, 14 percent of the water treated by water systems is lost to leaks. Some water systems have reported water losses exceeding 60 percent. Leak detection and replacing aging infrastructure are important aspects of water loss control.
- Water rates: One of the most effective ways to reduce demand for water is to establish rates that escalate as more water is used.

Conducting a review of existing techniques and evaluating additional measures that would be appropriate for the water utility to implement is considered to be relatively low-cost, and the identified measures could ultimately result in decreased overhead costs. However, the cost of implementing the measures could range from relatively inexpensive (e.g. leak detection and notification programs) to very costly (e.g., replacing outdated and leaking infrastructure). Implementing the right mix of techniques that is responsive to water utilities' needs and financial constraints is considered important in the success of this strategy. Additionally, this adaptation strategy will assist in meeting water utilities' obligations under the Water Use and Efficiency Act to "reduce leakage to 10 percent" (R.I.G.L. § 5828, 2009). Under this strategy, it is recommended that a water utility take the following steps (if they have not already done so): 1) conduct a water audit and begin tracking water use; 2) fix leaks and other sources of waste; and 3) use reliable data to identify appropriate strategies and benchmarks moving forward, including water metering and leak detection.

There are potentially critical economic and social considerations that could impact a utility's ability to implement water efficiency programs. Many of the major water utilities in the state have expressed that economic constraints are the primary obstacles faced by drinking water utilities (Phase 1 Report). One utility manager described the issue of rate increases as "trying to get blood from a turnip" – their utilities have raised rates all they can in trying to maintain aging infrastructure. Raising rates can also have adverse socio-economic impacts on vulnerable populations. For example, due to changing demographics and loss of industry, East Smithfield Water District has an aging and outdated infrastructure that is supported by a largely elderly population living on fixed incomes. The water district now sells only half of the amount of water that was once sold in the 1980s and 90s, and has been forced to raise water rates significantly over the past five years which could adversely impact the elderly population. The issue of water rates will be further explored under Adaptation Goal 3.

4.2.6 Strategy 6: Develop Outreach and Education Strategies for Demand Side Management

Demand side management programs are an effective and low-cost method for meeting increased water supply needs. Demand side management programs refer to water conservation programs that will cut down on waste and inefficiencies, and are targeted at utility customers. Public outreach is an essential component of any water conservation program as success is dependent on wide-ranging participation from customers. Outreach and education strategies typically include: basic information on household water usage, the best time of day to undertake water-intensive activities, and information on and access to water-efficient household appliances (EPA 2011). One of the benefits of this adaptation strategy is that it can be targeted to the community during projected periods of shortage, such as summer months, and during prolonged drought. Common demand side strategies include the following:

- Water efficient products: Customers and developers can reduce water use by installing water-efficient products such as low-flow toilets, showerheads, and front-loading washers. Water utilities can promote water efficient products through consumer rebate and outreach programs.
- Rainwater harvesting: Residential and commercial rainwater harvesting systems can be installed to collect rainwater. Systems can range from rain barrels connected to drain spouts for gardening and landscaping, to large systems that collect water for domestic usage. An important benefit of rainwater harvesting is that it decreases storm water volume and reduces non-point source pollution. For example, the Narragansett Bay Commission subsidizes rain barrels as a way to decrease stormwater runoff into the combined sewer overflow system (RIDP 2012).
- Landscape conservation programs: Programs that promote use of water efficient landscaping, including use of native and low-water-use plants and efficient irrigation systems (EPA 2002).[14] Development of grass watering policies can provide more targeting conservation targets during critical water or drought periods, and can be enforced with fines in coordination with municipalities.
- Irrigation equipment and techniques: These programs work with farmers to promote installation of more water efficient drip irrigation systems or more advanced equipment (e.g., micro-irrigation systems with weather-linked controls).

Under this strategy, drinking water utilities would develop targeted outreach and education programs to promote demand side water management. It is recommended that a utility first use a pilot project to identify the most effective communication strategies and target specific sectors that are considered crucial to water conservation efforts during drought or for long-term sustainability (i.e., commercial, institutional, industrial, public sectors). It is further recommended that the utility measure results and report them to the targeted sector and customers to promote awareness and buy-in. EPA's WaterSense Program could provide valuable resources for drinking water utilities that implement this adaptation strategy. The program assists drinking water utilities that become partners of the program by providing tools that can be used to promote water efficiency programs, including water efficient products and rainwater harvesting.[15] Additionally, water utilities could look for "double win" opportunities, whereby both water and energy usage is reduced. For example, the city of Phoenix worked with the Phoenix Children's Hospital to install a more efficient heating and cooling plant, which saved 5.6 million gallons per year.

This adaptation strategy is considered low-cost and is not anticipated to have adverse implications in the STAPLEE areas; in fact, this strategy is anticipated to have beneficial impacts especially for social and environmental areas due to the co-benefits associated with water efficiency strategies (e.g. social benefits such as reduced water and energy bills; environmental benefits such as reduced stormwater flows and

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[14] For more information see: <http://www.epa.gov/WaterSense/docs/water-efficient_landscaping_508.pdf>.
[15] For more information see: <http://www.epa.gov/watersense/>.

pollution). However, this adaptation strategy could adversely impact water utilities bottom-line. Participants in the Phase 1 utility meeting identified demand-side water reduction strategies as a "double-edged sword". If customers conserve water, then the utility sells less water, and is thus less able to meet financial obligations and sufficiently maintain infrastructure. There could also be administrative constraints related to implementing this adaptation strategy, as there would be additional personal and administrative demands on water utilities to develop and implement the public outreach and education (e.g., developing the program and maintaining communication with customers and stakeholders).

4.2.7 Adaptation Goal #2 Strategy Evaluation

Each adaptation strategy was assessed according to the STAPLEE criteria (refer to Table 4: Adaptation Strategy Ranking Framework) and results are presented in Table 11. Given that the technical, administrative, and economic capabilities of the state's water utilities vary, sometimes considerably, there are several "U's" (e.g. the effects of the strategy on those issues are unknown) for those areas. It is recommended that each water utility further consider the applicability of the STAPLEE rankings relative to their utility, to determine the priority adaptation strategies that could assist their utility in meeting adaptation goal #2.

The structural strategies have several unknowns which would require additional study in order to determine if they would be cost effective. Feasibility studies, environmental assessments, and a benefit cost analysis would need to be conducted before moving forward with any of the strategies. It is difficult to determine the potential losses due to drought and competing water uses since there are no historical losses to analyze.

Table 11. Adaptation Goal #2 strategy evaluation

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
1. Implement Local Proposed Alternative Water Supply Sources (P, O)	0	+1	U	0	+1	U	U	+2
2. Implement Regional Alternative Water Supply Sources (P, O)	-1	U	-1	U	+1	-1	U	-2
3. Evaluate Opportunities for Water Reuse (P, O, S, E)	U	+1	U	U	+1	U	+1	+3
4. Develop Emergency Water Agreements (P, O)	+1	+1	U	0	U	+1	+1	+4
5. Enhanced Operations and Systems Management for Water Efficiencies (P, O, S, E)	+1	+1	U	U	+1	U	+1	+4
6. Develop Outreach and Education Strategies for Demand Side Management (O, S, E)	+1	+1	U	U	+1	U	+1	+4

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: Significantly Adverse = -1; Insignificant= 0; Significantly Beneficial= +1; Unknown= U.

The results indicate several beneficial, low-cost adaptation strategies that could be implemented to adapt to drought or low water scenarios. Working with surplus water utilities to develop emergency water agreements would be a cost-effective strategy with opportunity for immediate impact. Developing and implementing outreach and education strategies to encourage demand-side management would also be a cost effective way of helping customers and stakeholders prepare for and adapt to changing conditions, and could promote greater awareness of water issues and pricing. Evaluating opportunities for enhanced operations and systems management for increased water efficiency could provide both short-term and long-term impact and possibly decrease operating costs. Developing new water sources through local and regional solutions identified by the RIWRB, as well as through water reuse strategies would provide more costly and longer term solutions; however, developing these new water sources could be necessary for those utilities identified as highly vulnerable to drought.

4.3 Adaptation Goal #3: Use Integrated Management and Planning to Increase Adaptive Capacity

The Phase 2 impacts assessment results show that Rhode Island water utilities are currently vulnerable to a variety of hazards (drought, riverine and coastal flooding, sea level rise, and hurricanes), and that climate change is projected to increase the risks that these hazards pose to water utilities. To effectively manage the increasing risk, water utilities could increase their adaptive capacity by using integrated management and planning frameworks as a way to comprehensively plan for climate impacts and increase the capacity of their systems. This adaptation goal recognizes that building institutional capacity is a fundamental enabling component for sustainable water resource management. Planning and capacity building strategies that promote integrated water resources management could provide cost-effective methods for building resilience to longer term climate change. Effective adaptation for water utilities will require using a comprehensive, integrated framework to examine water management adaptation options, including changes in operations, demand management opportunities, and changes in infrastructure. Due to the potential need for increased investment in infrastructure, decision-making frameworks should require robust community engagement and multidisciplinary and multi-sectoral collaboration.

The strategies in this section could assist Rhode Island drinking water utilities to use integrated management and planning to increase their adaptive capacity.

4.3.1 Strategy 1: Integrate Climate Change into Water Utility Planning Efforts

The largest water utilities in Rhode Island are required to develop WSSMPs and Infrastructure Replacement Plans. Under this strategy, water utilities would consider the potential impacts of climate change in these required plans.

Preparations of WSSMPs are required for the major water utilities (e.g., utilities that produce, treat, transport, and supply over 50 million gallons per year) in Rhode Island under the Water Supply System Management Planning Act (R.I.G.L. 46-15.3) and subject to the rules and regulations promulgated by the RIWRB. The purpose of the WSSMPs is to ensure that the largest suppliers address ongoing management for operating their water systems, including: maintaining capacity and capability, protecting source and potable water quality, resource conservation, and emergency situations. WSSMPs are required to be updated every five years. WSSMPs could be an extremely useful tool for water utilities to evaluate climate change risks, as the process calls for “planning to be done for the protection of water sources, anticipating future demands, reducing peak demands, and identifying potential future service areas” (RIDP 2012).

The major water utilities are also required under the Clean Water Infrastructure Act (R.I.G.L. 46-15.6) to develop Infrastructure Replacement Plans, and are subject to the rules and regulations promulgated by HEALTH. Infrastructure Replacement Plans are required to include the following: principal components of the water system; age and condition of the existing components and the necessity for replacement of the components within a 20 year time frame; replacement plan that is evaluated and prioritized over a minimum of 5 year intervals; and a financial forecast based on the analysis of the condition and life expectancy of the existing facilities, prioritized needed repairs and replacements and improvement requirements on an annual basis over the next 20 years consistent with their respective life expectancy.[16] Infrastructure Replacement Plans must also be consistent with WSSMPs.

Under this strategy, water utilities would evaluate their priority vulnerabilities, at-risk infrastructure, and the anticipated time horizon of projected impacts and incorporate adaptation strategies into WSSMPs and Infrastructure Replacement Plans. This adaptation strategy is not anticipated to have adverse implications

[16] For more information see: <http://sos.ri.gov/documents/archives/regdocs/released/pdf/DOH/DOH_151_.pdf>.

to the STAPLEE areas. This strategy could have beneficial social impacts due to the potential for minimizing disruptions in water service to customers caused by natural disasters and/or long-term projected changes in sea level rise. There could be administrative constraints related to this adaptation strategy if personnel lack the time and resources to incorporate climate change impacts into the planning processes. There could also be economic constraints related to implementing the proposed adaptation options.

4.3.2 Strategy 2: Coordinate WSSMPs with Community and Municipal Plans

Under this strategy, water utility managers would coordinate WSSMPs, including the projected impacts of climate change for their water utility, with other community and municipal planning efforts. Specifically, water utility managers could coordinate with the development of Community Comprehensive Plans (CCPs), Municipal Capital Improvement Plans, and Municipal Hazard Mitigation Plans on projected climate change impacts. Coordination with other community planning efforts would also be encouraged under this strategy. A brief summary of recommended community and municipal planning efforts is included below:

- CCPs: serve as the basis for land use regulation by 39 Rhode Island municipalities and are binding on Rhode Island agencies by requiring conformance of their programs and projects to the CCPs (RIWRB 2012). Although not all CCPs have included a water supply section to date, a recent law[17] requires that major land use decisions be linked to water availability, and it is anticipated that more CCPs will include a water supply section. Water utility managers are currently encouraged by DEM, HEALTH, RIDP, and RIWRB to coordinate WSSMPS with CCPs, although it is not clear how effective coordination has been to date.
- Municipal Capital Improvement Plans: many Rhode Island municipalities develop five year capital improvement plans, which identify infrastructure that is in need of immediate repair and upgrade, sustained maintenance and protection needs for on-going and new capital investments, and future large-scale planned expenditures. Water and sewer facility and infrastructure improvements are included in these planning efforts for publicly owned and operated systems.
- Municipal Hazard Mitigation Plans: are developed by Rhode Island municipalities pursuant to the Federal Disaster Mitigation Act of 2000 (P.L. 106-390) and to achieve eligibility for the FEMA hazard mitigation grant programs. The purpose of the plans is to identify and implement hazard mitigation measures to eliminate or reduce the effects of future disasters. Natural hazards such as severe storms, hurricanes, and flooding are generally addressed in the plans.

To date, the potential impacts of climate change have not been incorporated into any of the above listed Rhode Island planning efforts. Under this strategy, water utilities would coordinate with the community and municipal personnel responsible for developing these plans to share the projected impacts of climate change on their utilities and identify at-risk infrastructure, as well as adaptation strategies that are planned or underway. Increased coordination, particularly as it relates to CCPs and Municipal Capital Improvement Plans, could lead to more coordinated infrastructure and capital decisions. Projected climate change impacts identified in the *Safe***Water** RI project could also help inform planning and decision-making of the community and municipal planning efforts. Pursuant to the amended Comprehensive Planning Act (§ 45-22.2-8), municipalities are required to consider natural hazards, such as flooding and sea-level rise, in their community plans and have until June 2016 to bring their comprehensive plans into conformance. The required updates offer a beneficial opportunity for water utilities and community planners to coordinate to evaluate the risks of climate change impacts at the community level.

[17] The Rhode Island Comprehensive Planning and Land Use Act was amended by the 2009 Rhode Island Code (R.I.G.L. § 45-22.2-6).

This adaptation strategy is not anticipated to have adverse implications to the STAPLEE areas. There could be significantly beneficial social, environmental, and economic impacts under this strategy due to the potential for a more integrated approach to community and financial planning and the potential to mitigate the projected impacts of climate change at a broader scale. There could be administrative constraints related to this adaptation strategy if personnel lack the time and resources to coordinate with the recommended planning processes.

4.3.3 Strategy 3: Evaluate Regionalization to Improve Capacity

Regionalization is defined by the RIDP as "any form of cooperation between multiple water systems, including, but not limited to, activities resulting in a change in ownership" (RIDP 2012). Regionalization options can include any or all of the following:

- One water system acquiring the ownership and control of another;
- Multiple systems developing an agreement for sharing;
- Multiple systems physically interconnecting their infrastructures;
- Administrative combination of multiple water systems as a way to improve planning, operation, and/or management.

There are approximately 87 small community water supply services in Rhode Island, and the issue of regionalization has been recognized as a potential way to increase capacity of these smaller utilities. Regionalization has also been recognized as a way to increase capacity at some of the larger utilities that face significant financial and administrative constraints. Participants in the Phase 1 water utility meeting identified regionalization as a management strategy that warranted further consideration, and regionalization is also considered as a potentially advantageous strategy for stressed water utilities in *Rhode Island Water 2030* (RIDP 2012).

The potential benefits and impacts of regionalization must be considered on a case by case basis, as the impacts could vary significantly. The primary benefits could include: economies of scale (e.g., costs will be spread over a larger population base), greater access to capital, increased supplemental emergency water sources, and increased number of and/or access to skilled employees. However, regionalization could also have several disadvantages, such as the potential for: debt from acquisition, job loss, political barriers, and differing management goals between utilities.

Under this strategy, small or stressed water utilities would evaluate opportunities for regionalization to increase their capacity. Evaluation of the STAPLEE criteria would need to be undertaken on a case by case basis, as the criteria could be significantly different for each utility.

4.3.4 Strategy 4: Develop a Sustainable Financial Strategy

The Phase 2 results identified 34 drinking water utilities that have infrastructure that is currently at-risk, or projected to be at-risk in the future from climate hazards (refer to Table 5. Total infrastructure losses per hazard). Under this strategy, water utilities would develop a comprehensive financial strategy to implement adaptation measures and ensure sustainability of operations and service. This strategy involves incorporating new investments into a successful financial strategy that ensures revenues cover costs over the long term, including consideration of pricing and rate structures. There are several financial options and considerations that a water utility could evaluate under this adaptation strategy:

- Water rates. The average cost of water is "extremely" low in Rhode Island compared to neighboring states (RIDP 2012). Water rates in the state have been developed to reflect the average cost of water; or, the total cost divided among users without regard for how users influence the costs. Another contributing factor for the state's artificially low prices is that in many cases a substantial portion of the initial capital investment was heavily subsidized by federal grants, allowing utilities to provide service without passing on the full cost of the infrastructure. Additionally, operations and maintenance costs were often not included in developing water rates.

- Federal water infrastructure grants, loans, and loan guarantees. There are several sources of funding that could be applicable to help water utilities meet their infrastructure needs. These include the U.S. Department of Agriculture's Rural Development Water and Environmental Program, the Department of Housing and Urban Development's Community Development Block Grant Program, EPA's Clean Water State Revolving Fund Program and Drinking Water State Revolving Fund Program.[18]
- Rhode Island's Water Facilities Assistance Grant Program. This grant program is administered by RIWRB. Funds are available for emergency interconnections, whereby a 25 percent grant is allowed for a one way connection, and up to a 50 percent grant is available for a two way connection.
- Expand funding options. Water utilities in the United States have used a variety of options to fund infrastructure improvements, in addition to rates, fees, and grants. These options have included property taxes, insurance, private investment, and debt-based capital financing.
- Innovative financing models. There are a variety of innovative financing models that are being considered or implemented (primarily in pilot programs) across the country. For example, incorporating value-added and ecosystem services moves utility pricing beyond volumetric pricing to link revenue to the additional service (e.g, watershed services such as storage and filtration).

In Phase 1 of the *Safe***Water** RI project, water utilities identified economic constraints as the primary obstacle of their utility. Climate change is projected to put additional economic strain on water utilities to cope with increasing drought and flood conditions, as well as more severe impacts from storms and hurricanes. Given the existing economic constraints of water utilities, it is anticipated that to develop a sustainable financial strategy that incorporates projected climate change impacts, one or more of the financial options listed above will need to be explored. While there are significantly beneficial economic, social, and environmental benefits that could be realized under this alternative by having a comprehensive financial model that is able to support the necessary infrastructure investments and adaptation measures necessary for long-term sustainability, there could also be significantly adverse impacts. For instance, there could be social and political obstacles in raising water rates if customers and elected officials do not feel that the new rates would be equitable or worthwhile. There could also be administrative challenges if utility personnel do not have the time or skill-set to develop the financial strategy.

This strategy is considered a "win-win" strategy as it would also help utilities meet the requirement of the 2009 Water Use and Efficiency Act, which requires that utilities establish revenue stabilization.

4.3.5 Strategy 5: Develop Education and Outreach Strategies of Projected Climate Change Impacts

As discussed in Strategy 4 above, it could be critical that water utility customers and stakeholders, including elected officials and board members, recognize the potential vulnerabilities of the utility to climate change impacts, so that water utilities can develop sustainable financial strategies and implement adaptation measures. Under this strategy, water utilities would develop education and outreach strategies on the projected climate change impacts to the state and/or the water utility. Education and outreach could be directed both internally (e.g., staff and board members) and externally (customers and other stakeholders such as environmental organizations). Public education and outreach is considered an essential component of any sustainable financial strategy. Outreach and education strategies could

[18] For more information see: http://www.epa.gov/region1/eco/drinkwater/pdfs/waterfundletterweb.pdf.

include: basic information on climate change, the projected changes (e.g., temperature, precipitation, sea level rise, flooding, and hurricanes), and the utilities vulnerability to those changes.

This adaptation strategy is considered low-cost and is not anticipated to have adverse implications to the STAPLEE areas; in fact, this strategy is anticipated to have beneficial impacts especially for social and environmental areas due to the co-benefits associated with educating the public on climate change impacts. There could be administrative constraints related to implementing this adaptation strategy however, as there are would be additional personnel and administrative demands on water utilities to develop and implement the public outreach and education (e.g., developing the program and maintaining communication with customers and stakeholders).

4.3.6 Adaptation Goal #3 Strategy Evaluation

The five adaptation strategies in this section were assessed according to the STAPLEE criteria (refer to Table 4: Adaptation Strategy Ranking Framework) and results are presented in Table 12. Given that the technical, administrative, and economic capabilities of the state's water utilities vary, sometimes considerably, there are several "U's" (e.g. the effects of the strategy on those issues are unknown) for those areas. Evaluation of adaptation Strategy 3 would need to be undertaken on a case by case basis, as the criteria could be significantly different for each utility. It is recommended that each water utility further consider the applicability of the STAPLEE rankings relative to their utility, to determine the priority adaptation strategies that could assist their utility in meeting adaptation goal #3.

Table 12. Adaptation Goal #3 strategy evaluation

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
1. Integrate Climate Change into Water Utility Planning Efforts (O, S, E)	+1	+1	U	0	+1	+1	+1	+5
2. Coordinate WSSMPs with Community and Municipal Plans (O, S, E)	+1	+1	U	0	+1	+1	+1	+5
3. Regionalization to Improve Capacity (P, O, E)	U	U	U	U	U	U	U	U
4. Develop a Sustainable Financial Strategy (O, S, E)	U	+1	U	U	+1	+1	+1	+4
5. Develop Education and Outreach Strategies of Projected Climate Change Impacts (O, S)	+1	+1	U	U	+1	+1	+1	+5

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: Significantly Adverse = -1; Insignificant= 0; Significantly Beneficial= +1; Unknown= U.

The results show that all of the adaptation strategies except for Strategy 3 would be cost-effective and significantly beneficial to implement. More information would be needed for a complete evaluation of Strategy 3.

5.0 STRUCTURED DECISION-MAKING

It is recommended that water utilities use a structured decision-making process to address climate change. The iterative steps below illustrate the technical and management decisions and actions that are recommended in formulating, and implementing, the specific adaptation strategies that would be most beneficial to the water utility.

Step 1: ID priority vulnerabilities and at-risk infrastructure	• What is your utility's degree of risk (e.g., priority vulnerability score) to each hazard? • What are the anticipated quantitative impacts to your utility? • What is the expected time-frame for the impacts?
Step 2: Develop adaptation goals	• Identify the adaptation goals that are the most responsive to your utility's vulnerabilities.
Step 3: Build partnerships	• Identify the relevant stakeholders for your utility. • Consider which stakeholders are the most influential to building resilience for your utility.
Step 4: Evaluate adaptation strategies	• ID win-win strategies (e.g., help meet other goals or regulatory requirements). • Quantify the costs of each adaptation option relative to the potential risks of impacts. Consider using the STAPLEE criteria as a way to prioritize adaptation strategies. • Determine the expected life-span of each option. • Determine “threshold points” for implementing the adaptation option (e.g. indicators).
Step 5: Develop sustainable financial model	• Develop a financial model for your utility that integrates the costs of climate change impacts and projected infrastructure requirements.
Step 6: Implement adaptation options	• Ensure that the adaptation options meet your adaptation goals. • Coordinate implementation within the constraints of the financial model and anticipated time horizon of climate impacts.
Step 7: Monitor and evaluate	• Monitor and evaluate the effectiveness of each adaptation strategy.
Step 8: Integrate new information	• Use an adaptive managment framework to integrate new information. • Feed new information into decision support tools such as HAZUS-MH.

Figure 3. Structured decision-making process to integrate climate change into water utility planning.

While all of the steps above are important to successfully integrating climate change considerations into water utility decision-making, the critical importance of building partnerships and developing sustainable financial models has been highlighted as a cross-cutting issue in this report.

6.0 NEXT STEPS

The *Safe***Water** RI project is iterative, with each phase building on the previous phase(s). The Phase 1 data collection efforts established a baseline of understanding of the viewpoints and activities of water utility partners; the Phase 2 impact assessment identified the priority vulnerabilities and risks to water utility infrastructure, and the Phase 3 report has identified priority vulnerabilities and potential adaptation goals and strategies that water utilities can use to increase their resilience to climate change impacts. Phase 4 will build off of these efforts by developing education and outreach strategies that drinking water utilities can use to influence stakeholder perceptions of climate change and extreme weather. Historically, the largest barriers to changing water utility rates and service offerings have been consumer apathy and resistance to change. Phase 4 will seek to develop strategies that go beyond typical customer communication to assist customers, as well as water utility personnel and other stakeholders, to understand the challenges posed by climate change and to help enable implementation of adaptation strategies.

TETRA TECH

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