New England Climate Adaptation PROJECT

Summary Climate Change Risk Assessment

Wells, Maine

March 2014

PRODUCED BY:

Massachusetts Institute of Technology Science Impact Collaborative

Consensus Building Institute

The Wells National Estuarine Research Reserve System

Acknowledgements

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About the MIT Science Impact Collaborative

The Massachusetts Institute of Technology Science Impact Collaborative (MIT SIC) is a research group focused on developing and testing new ways of harmonizing science, politics, and public policy in the management of natural resources and resolution of environmental disputes. MIT SIC's tools and approaches include collaborative adaptive management, joint fact-finding, scenario planning, collaborative decision-making, multi-stakeholder engagement, and role-play simulation exercises.

MIT SIC was established in 2003 with initial support from the United States Geological Survey. Today, the research group has numerous partners and supporters, ranging from the U.S. National Estuarine Research Reserve System to the Dutch research organization TNO. By engaging in community-based action research projects, MIT SIC researchers—including doctoral students, masters students, and faculty from the MIT Department of Urban Studies and Planning—train emerging environmental professionals while simultaneously testing the latest environmental planning methods and providing assistance to communities and policy-makers who seek their help.

Visit the MIT Science Impact Collaborative website for more information: http://scienceimpact.mit.edu

About the Consensus Building Institute

The Consensus Building Institute (CBI) is a not-for-profit organization founded in 1993 by leading practitioners and theory builders in the fields of negotiation and dispute resolution. CBI's experts bring decades of experience brokering agreements and building collaboration in complex, high-stakes environments — and possess the deep understanding required to tackle negotiation and collaboration challenges in their practice areas. CBI's founder, managing directors, and many of their board members are affiliated with the Program on Negotiation at Harvard Law School and the MIT-Harvard Public Disputes Program.

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About the Wells National Estuarine Research Reserve

The National Estuarine Research Reserve System (NERRS) is a network of 28 areas representing different biogeographic regions of the United States that are protected for long term research, water-quality monitoring, education, and coastal stewardship. The reserve system is a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states. Reserve staff work with local communities and regional groups to address natural resource management issues, such as climate change, non-point source pollution, habitat restoration, and invasive species. Through integrated research, stewardship, and education, the reserves help communities develop strategies to deal successfully with these coastal resource issues. Reserves provide adult audiences with training on coastal and estuarine issues of concern in their local communities. They offer educational programs for students, teachers, decision-makers, and community members. Reserves also provide long term weather, water quality, and biological monitoring as well as opportunities for scientists and graduate students to conduct research in a "living laboratory."

The Wells National Estuarine Research Reserve works to expand knowledge about coasts and estuaries, engage people in environmental learning, and involve communities in conserving natural resources, all with a goal of protecting and restoring coastal ecosystems around the Gulf of Maine. The Wells Reserve protects 2,250 acres of salt marsh, freshwater wetland, beach, dune, forest, and field.

Visit the Wells Reserve website for more information: wellsreserve.org

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Executive Summary

The Town of Wells faces several climate-related risks, the most notable being the risk of increased flooding from intense precipitation events, coastal storm surges, and sea level rise. Wells also faces the potential for a significant increase in the occurrence of extreme heat events, with the worst case climate projections indicating that Wells could experience more than ten times as many days over 90 degrees (°) Fahrenheit (F) per year by the end of the century. Further, the sea level near Wells is projected to rise by as much as 5 feet by 2085, which will have considerable impacts on Wells' barrier islands and the homes that have been built there. These changes, if not prepared for and managed, could threaten Wells' population, buildings, infrastructure, landscape, property tax-base, and ecosystem health. While Wells has improved its physical infrastructure and services in response to related historical weather events, there is much more that can and needs to be done.

This Summary Risk Assessment presents how the climate could change in Wells over the 21st century, and outlines the town's key climate change risks as well as possible adaptation options to address those risks. This assessment was developed by the New England Climate Adaptation Project with the primary objective of providing targeted content for a role-play simulation exercise for Wells residents. While the information gathered by this project alone is not sufficient to guide Wells' planning and adaptation efforts, it may begin to inform local officials and town residents about potential future climate risks and adaptation options. Wells could benefit from a more detailed vulnerability assessment.

This report consists of two sections. Section 1 outlines potential future climatic conditions of Wells based on climate change projections downscaled to the nearest meteorological station of Portland, Maine, including historical and future trends for temperature and precipitation. Sea level rise and storm surge projections are based upon the tidal gauge in Portsmouth, NH. Climate change and sea level rise projections are presented for two scenarios—a high emissions scenario (Global Emissions Scenario A1fi reflecting a 940ppm CO_2 concentration by 2100) and a low emissions scenario (Global Emissions Scenario B1 reflecting a 550ppm CO_2 concentration by 2100). These scenarios are used to represent uncertainty concerning the amount of future global greenhouse gas emissions. Projections are presented in terms of three time scales –- short term (2010-2039), medium term (2040-2069), and long term (2070-2099) -- to capture change over time. The historical baseline refers to the time period between 1980 and 2010. For a detailed discussion on downscaling see Appendix 1.

Section 2 discusses how future climatic changes (including those in temperature, precipitation, and sea level) combine with other factors (such as built environment, economics, demographics, and natural context) to create integrated risks and increased vulnerability for Wells. Vulnerabilities largely stem from flood-related impacts leading to costly infrastructure damages, public health risks, and extensive ecosystem deterioration. In addition, Wells is expected to see more frequent heat waves, as well as potential droughts, and changes to marine habitats.

While climate change may have some benefits—such as a longer summer tourist season and reduced snow removal maintenance costs—overall climate-related changes are predicted to lead to large-scale, costly damages. Wells has begun to consider future sea level rise and increased storm precipitation in its infrastructure planning, but there is still more potential to adopt a wider range of adaptation options. Both physical infrastructure and policies may need to be modified to address projected climate changes. The vulnerabilities and adaptation options for Wells discussed in Section 2 were developed based on input from town officials and Wells' experience with past climate-related issues, as well as a review of published documents, including the 2011 New England Great Bay Report and Maine's 2009 Climate Future Assessment. Examples of adaptation options include moving out of vulnerable areas (i.e. buybacks), increasing flood insurance, expanding wetlands, and investing in flood-protection infrastructure, retrofits, and efficiency measures.

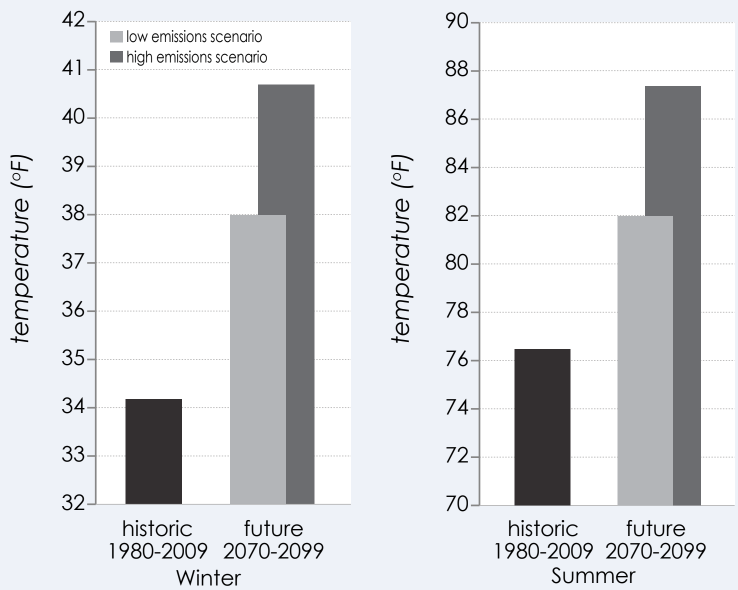
Even though some climate change impacts seem to be a long way off, many adaptation measures may take years of planning, coordination, and investment in order to come to fruition. Additionally, the choices and investments Wells makes today will either increase or decrease the town's vulnerability to current and future climate-related risks. Wells can increase its resilience in the face of a changing climate, but doing so will require that residents, business owners, and local and regional agencies work together and begin preparing for a changing climate now rather than waiting to confront the challenge after the damage has been done.

What do climate projections tell us about Wells by the end of the century?

A Warmer Wells. Average annual maximum temperatures are expected to increase by between 4.3 and 8.5°F under the low and high emissions scenarios, respectively.

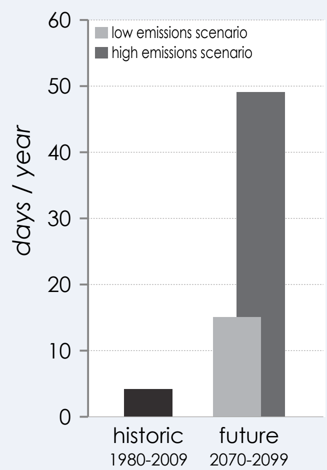
Warmer Summer Nights. Climate change will have a greater warming influence on nighttime minimum temperatures than daytime maximum temperatures. As a result summer nights will remain much warmer than they have been in the past.

Average Daily Highs (max temp)

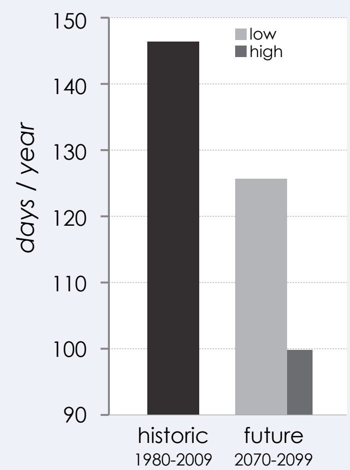


More Days Above 90°F. Fewer Below 32°F. In the long term, Wells may experience a more than tenfold increase in the number of days with extreme heat (above 90°F) from 4 days to 49 days per year and one third fewer days of extreme cold (below 32°F), decreasing from an average of 147 to about 100 days per year under the high emissions scenario.

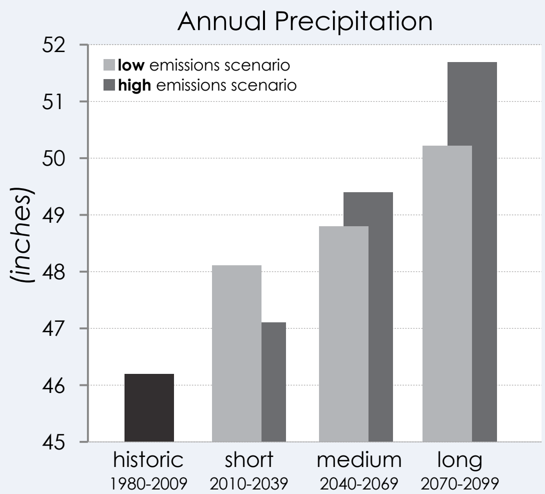
Days of Extreme Heat (>90°F)



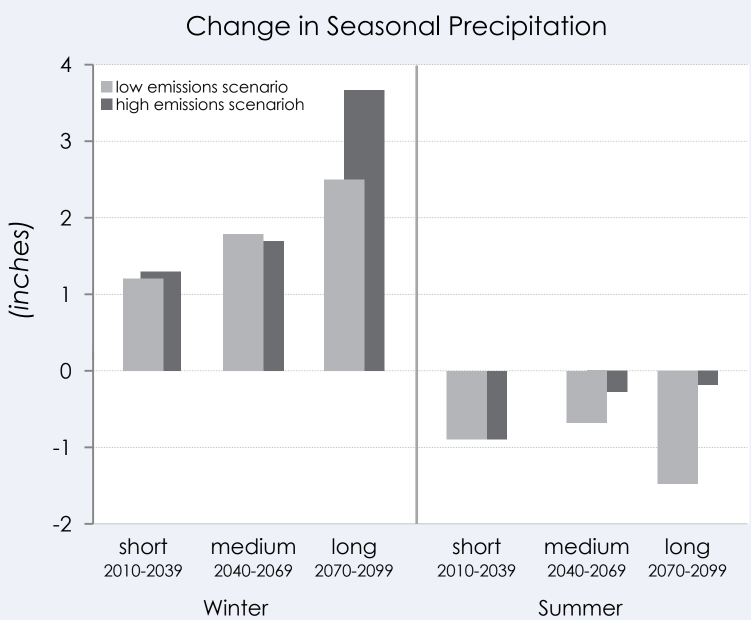
Days of Extreme cold (<32°F)



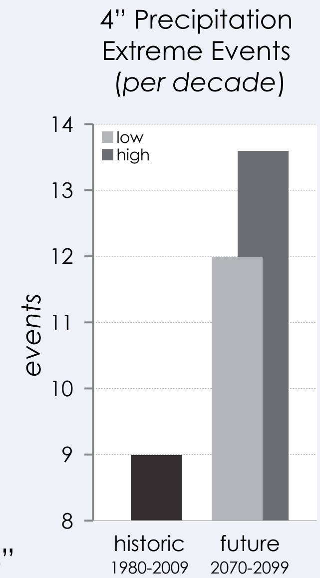
More Precipitation. Under both the high and low emissions scenarios, annual precipitation is expected to increase. Under the high emissions scenario, average annual precipitation may be as much as 12% higher than the historical baseline (5.5 more inches of rain per year).



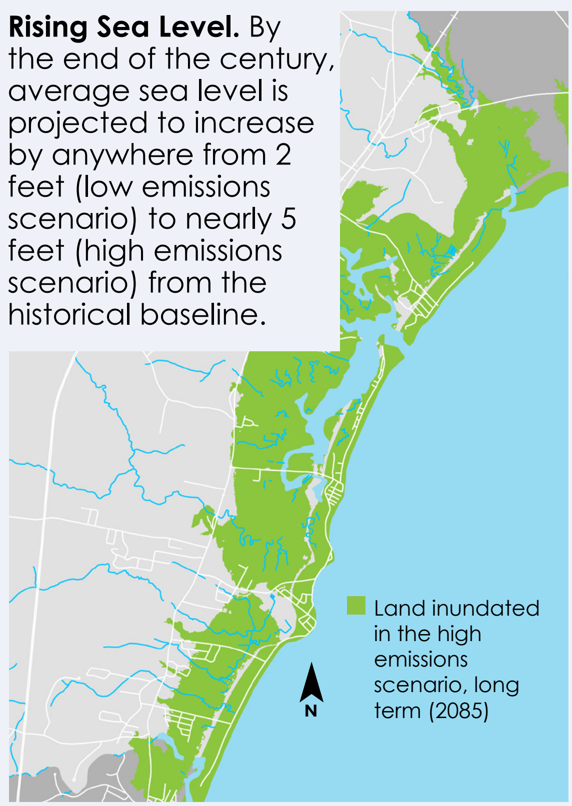
Wetter Winters. Drier Summers. Wells is projected to see wetter winters and slightly drier summers compared to the baseline.



More Extreme Precipitation. Under the high emissions scenario, Wells is projected to see a doubling in the number of events per year where 2" of precipitation fall in 48 hours. Wells is further projected to see a 50% increase in the number of events per decade where 4" of precipitation fall in 48 hours.



Rising Sea Level. By the end of the century, average sea level is projected to increase by anywhere from 2 feet (low emissions scenario) to nearly 5 feet (high emissions scenario) from the historical baseline.



What are the major risks for Wells and what can be done?

Flooding

Increased riverine and coastal flooding is expected to be the greatest climate change risk in Wells. Wells is vulnerable to flooding primarily due to its dense development along thin coastal barrier islands. In the future, more frequent heavy precipitation events and sea level rise are expected to increase the frequency and magnitude of flooding along the coast.

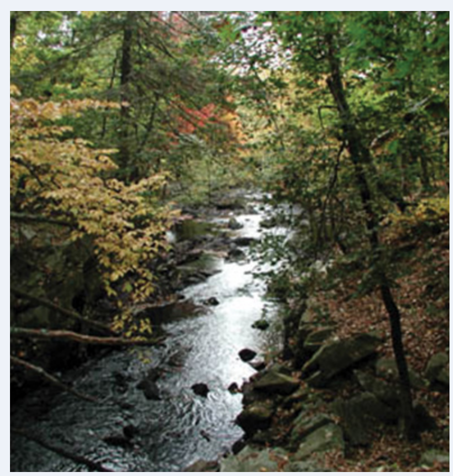
Communities along the coast of Wells—including Wells Beach, Moody Beach, Drakes Island, and Wells Harbor—are projected to experience the greatest damages from future tidal and surge flooding due to sea level rise. Inland areas, such as the Little River, may see increased flooding from more frequent extreme precipitation events and greater tidal and surge inundation. Heavy rainfall can also result in significant stormwater runoff, especially within developed landscapes, which can also lead to flooding.

Accentuating climate impacts, change in Wells' landscape may increase flood risks. The expansion of impervious surfaces resulting from future development will exacerbate flooding by decreasing the infiltration capacity of the land. Further, the submersion of beaches and marshes due to sea level rise represents an elimination of natural defensive barriers, which makes coastal habitat and human settlement even more vulnerable to storm surges.

Examples of Adaptation Options

Sand Replenishment
ex: Ocean City, MD

Flood Resilient Building Design
ex: Providence, RI



Wetland Restoration
ex: Woonasquatucket,RI

Heat Waves and Warmer Temperatures

Wells is likely to see a rise in public health risks associated with heat-related illnesses and invasion of pests as year-round temperatures rise and Wells experiences more frequent extreme temperature events. In addition, more frequent and prolonged heat waves can damage electrical equipment and create additional pressures on sensitive ecosystems.

Tourism and Fiscal Diversity

The Town of Wells relies heavily on summer tourism and coastal property tax revenues, both of which are dependent on the condition of Wells' coast. Damages to coastal properties due to flooding and sea level rise could severely impact Wells' fiscal wellbeing. Warmer temperatures may increase the length of the summer tourist season, which could benefit businesses. However, tourism relies on Wells' natural attractions, such as its beaches, marshes, and natural areas, which may be degraded by flood-related impacts.

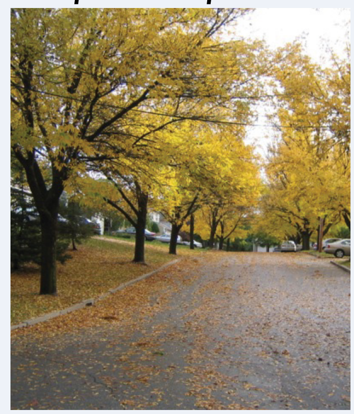
Drought

The threat of increased drought in Wells is driven by the projected decrease in summer precipitation combined with an increase in summer temperatures, which will result in more evaporation and transpiration. Drought, in general, may impact residents relying on groundwater wells. Prolonged drought could potentially impact the town's surface water supply for drinking water.

Marine Habitat Health

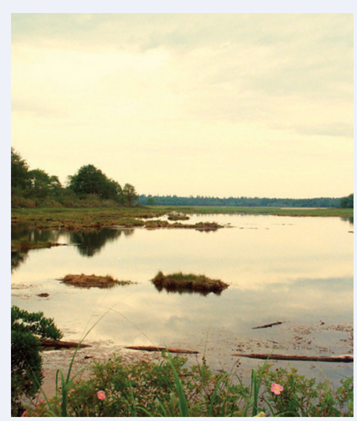
In the Gulf of Maine, changes in temperature, nutrient flows, and salinity associated with climate-related alterations in the Labrador Current will influence both the composition and distribution of marine species. While this study does not include a vulnerability analysis for marine habitats, past reports indicate that nearshore habitat and species with lower tolerance for temperature variation and pollution will be at a higher risk.

Examples of Adaptation Options



Tree Canopy
ex: Providence, RI

Water Conservation



Protected Salt Marshes
ex: Wells, ME

Section 1: Future Climate in Wells

This section highlights temperature and precipitation projections that have been downscaled for Wells, Maine, from the nearest meteorological station of Portland, Maine. Statistical downscaling translates coarse global climate model projections to the spatial scale of local weather station observations (Stoner et al., 2012). This is done by quantifying historical relationships[1] between large-scale weather features and local patterns. Two irreducible uncertainties govern the use of multiple projections in estimating future change. The first is the sensitivity of the climate to increased atmospheric concentration of CO_2, which is addressed through the use of multiple computational models. The second is predicting how much CO_2 and other greenhouse gases will be emitted over the next century, which is captured in multiple emissions scenarios. In order to capture the full range of future climate changes that Wells might experience during the 21st century, this project looks at the projections of four global climate models (GFDL, HdCM3, PCM, and CCSM3) and two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (A1fi, reflecting the highest projections of emissions and B1, reflecting the lowest projections of emissions) (Figure 1). Projections are presented in terms of three time scales—a short term (2010-

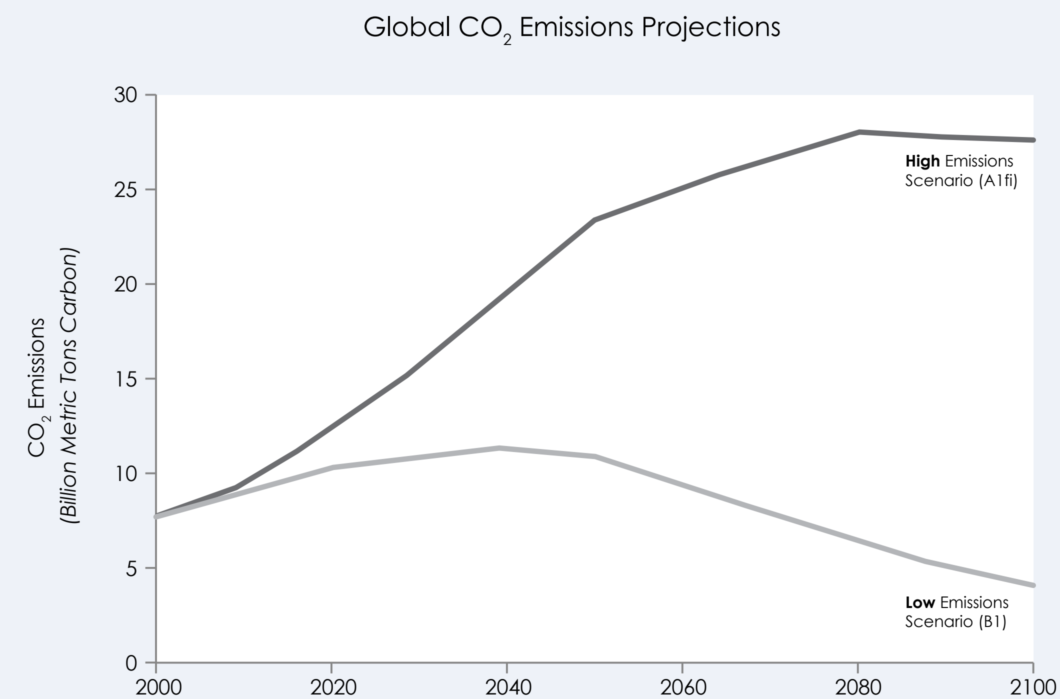


Figure 1. Global CO_2 Emissions Projected over a Century for High and Low IPCC Scenarios

1 It is worth noting that the historical period represents a relatively short and recent series of data relative to the period of anthropogenic greenhouse gas emissions – namely 1980-2009. That is, the historical period does not represent an era "pre-climate change," but is instead a baseline created due to available record-keeping. As an example, the New York Panel on Climate Change 2013 report states that for each decade between 1900 and 2011, the annual mean temperature rose by 0.4° Fahrenheit, precipitation increased by 0.7 inches, and sea level rose by 1.2 inches.

2039), medium term (2040-2069), and long term (2070-2099)—to capture change over time. A full description of the statistical downscaling methodology used for this report is provided in Appendix 1. Sea level projections are from a statistical analysis of the relationship between global temperatures and sea level rise (Appendix 1).

Temperature

Average Daily Temperatures

The average temperature in Wells is projected to increase over the next century for both the high and low emissions scenarios, although the high emissions scenario (A1fi) corresponds with larger and faster temperature increases (Figure 2). The low and high scenario temperature projections begin to diverge noticeably around the middle of the century. By midcentury (2040-2069) average daily lows (minimum) are expected to warm by between 3.0°F under the low emissions scenario and 4.8°F under the high emissions scenario. By the end of the century (2070-2099), daily lows are projected to warm by between 3.8°F (low emissions scenario) and 7.7°F (high emissions scenario). By the end of the century, maximum daily temperatures are projected to increase by 4.3°F under the low emissions scenario and upwards of 8.5°F under the high emissions scenario.

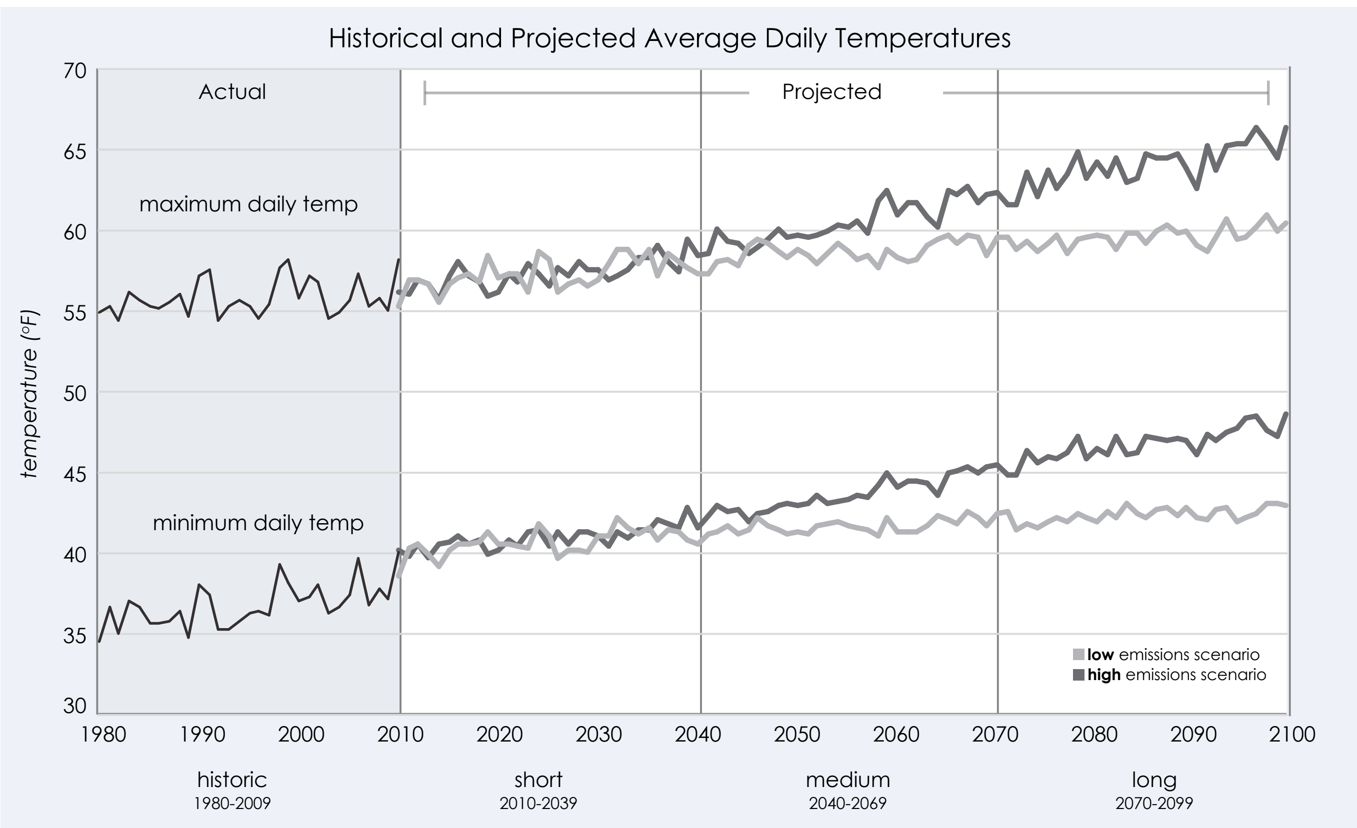


Figure 2. Historical (Actual) and Future (Projected) Daily Temperatures for Wells Based on Different CO_2 Emissions Scenarios and Timeframes

Seasonal Highs and Lows

Average minimum (daily low) and maximum (daily high) temperatures are projected to increase over the next century during both summers and winters. The projections indicate that climate change will have a greater influence on nighttime minimum temperatures than daytime maximum temperatures. This means that, especially in the long term, summer nights will be warmer than they have been in the past. By the end of the century (2070-2099), summer minimum daily averages in Wells will potentially increase from 57.1°F (1980-2009 historical average) to between 60.6 and 64.0°F. Summer maximum daily averages may increase by anywhere from 5.4°F to more than 10°F, raising the average daily high in the summertime from a historical average of 76.5°F to over 87°F under the high emissions scenario (Figure 3b). According to climate change projections, winter temperatures will be significantly affected by climate change in the long term, especially the minimum temperatures. By the end of the century, minimum winter temperatures will very likely increase from the historical average daily low of 16.5°F to between 21.5°F and 25.9°F. Due to this warming, cold winter nights may no longer function to eliminate pests such as the Hemlock Wooly Adelgid and ticks. Winter maximum temperatures will also rise, increasing from the historical average of 34.2°F to between 38.0°F and 40.7°F (Figure 3c). Together, the projections indicate a trend towards milder winters and fewer days of below-freezing weather. For both scenarios, but especially for the high emissions scenario, more winter days are projected to experience above-freezing temperatures (>32°F). As a result, more precipitation is expected to arrive in the form of rain rather than snow.

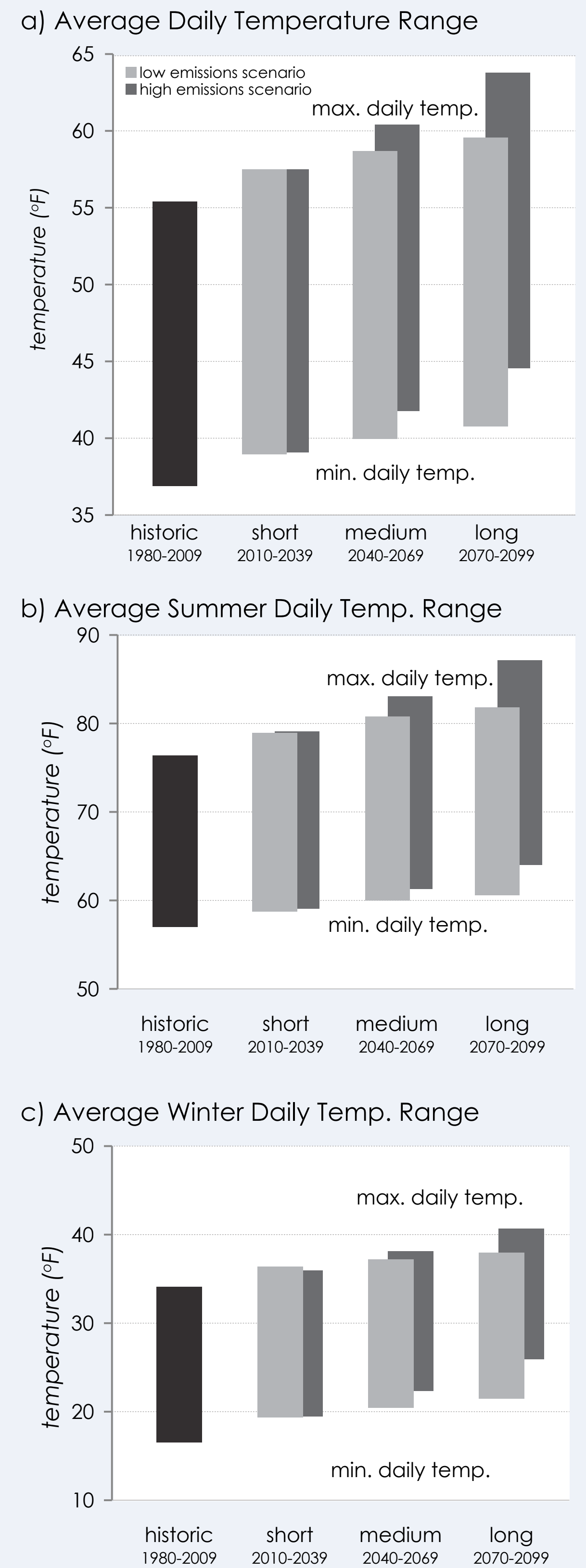


Figure 3. Future Average Daily Lows and Highs as Compared to Historical Baseline

Temperature Extremes

As temperatures increase, Wells is likely to experience more days of extreme heat and less of extreme cold. In fact, in the high emissions scenario by the end of the century, Wells could see more than 10 times as many days of extreme heat per year (with daily highs above 90°F) compared to what has occurred historically (Figure 4a). With regard to extreme cold events, Wells has historically experienced temperatures below 32°F on 147 days every year, on average. In the long term, under the low emissions scenario, the number of days Wells experiences temperatures below 32°F could decrease to 126 days per year. Under the high emissions scenario, this could decrease to 100 days, a 32% reduction from Wells' historical average (Figure 4b).

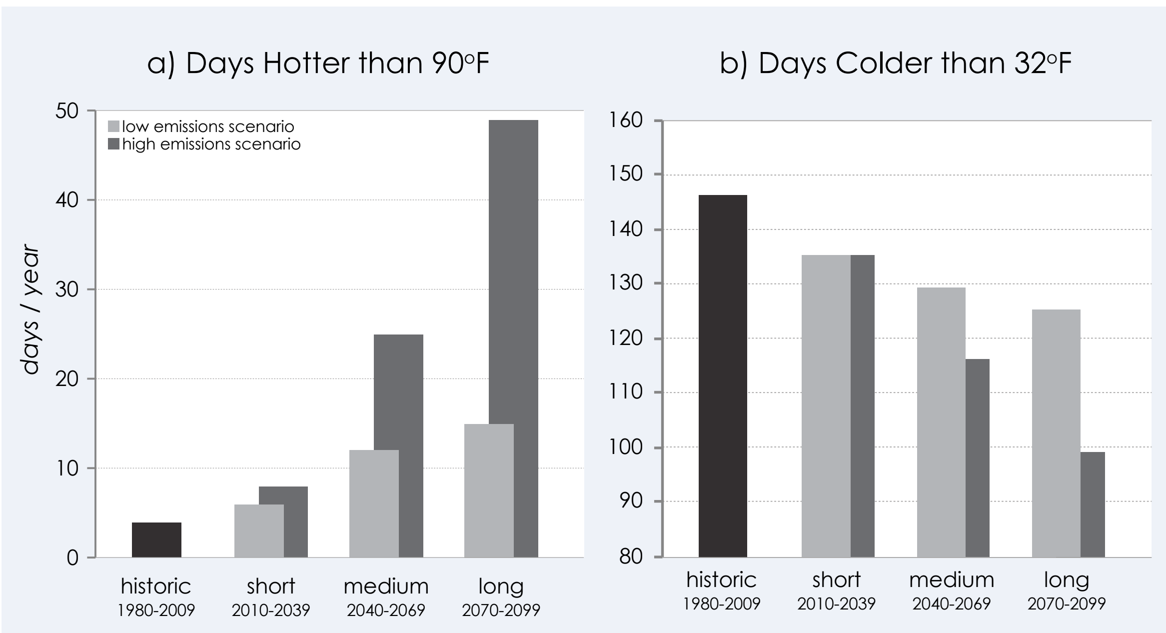


Figure 4. Extreme Temperature Events

Table 1. Potential Impacts of Higher Temperatures

Change	Potential Impacts of Higher Temperatures
↑	**Health impacts:** Extended and magnified heat events will increase risk of heat strokes, air pollution, and vector borne diseases.
↑	**Infrastructure damages:** Extreme heat and heat waves may damage roads and electricity transformers.
↓	**Water supply:** Higher temperatures will result in more precipitation falling as rain rather than snow. Snowpack functions as a natural reservoir to store water outside of manmade reservoirs for drinking water supply. The reduction of snowpack may reduce spring and early summer supplies. Higher average temperatures can also be associated with increased evaporation and transpiration which could further reduce water availability.
↓/↑	**Agriculture productivity:** Higher temperatures may cause a longer growing season, supporting agricultural benefits in crop production. Higher temperatures could also harm agricultural crops that are not suited for higher temperatures.
↑	**Ecosystem stress:** Higher temperatures can cause populations and habitats to migrate to lower temperature areas (high elevation or higher latitude), where possible. Ecosystems that cannot migrate or adapt to changing climatic conditions may degrade or collapse.
↓	**Snow removal costs:** Governments and property managers may be able to reduce their budgets for snow removal due to fewer extreme cold days.
↓/↑	**Heating and air conditioning bills:** People may save money if the warmer winter temperatures enable them to reduce the amount of energy needed to heat buildings. Conversely, higher summer temperatures may lead to higher air conditioning costs.

Precipitation

Average Daily Precipitation

There is high variability in average annual precipitation, both historically and in future projections (Figure 5). Comparing the average historic baseline (1980-2009) to short term, medium term, and long term projected averages reveals trends more clearly (Figure 6). The climate projections indicate a gradual increase in annual average precipitation through the century, with slightly higher increases under the high emissions scenario compared to the low emissions scenario (Figure 6). In the long term, projections indicate an increase of between 4.0 and 5.5 more inches of annual precipitation, raising the historical baseline by about 10%.

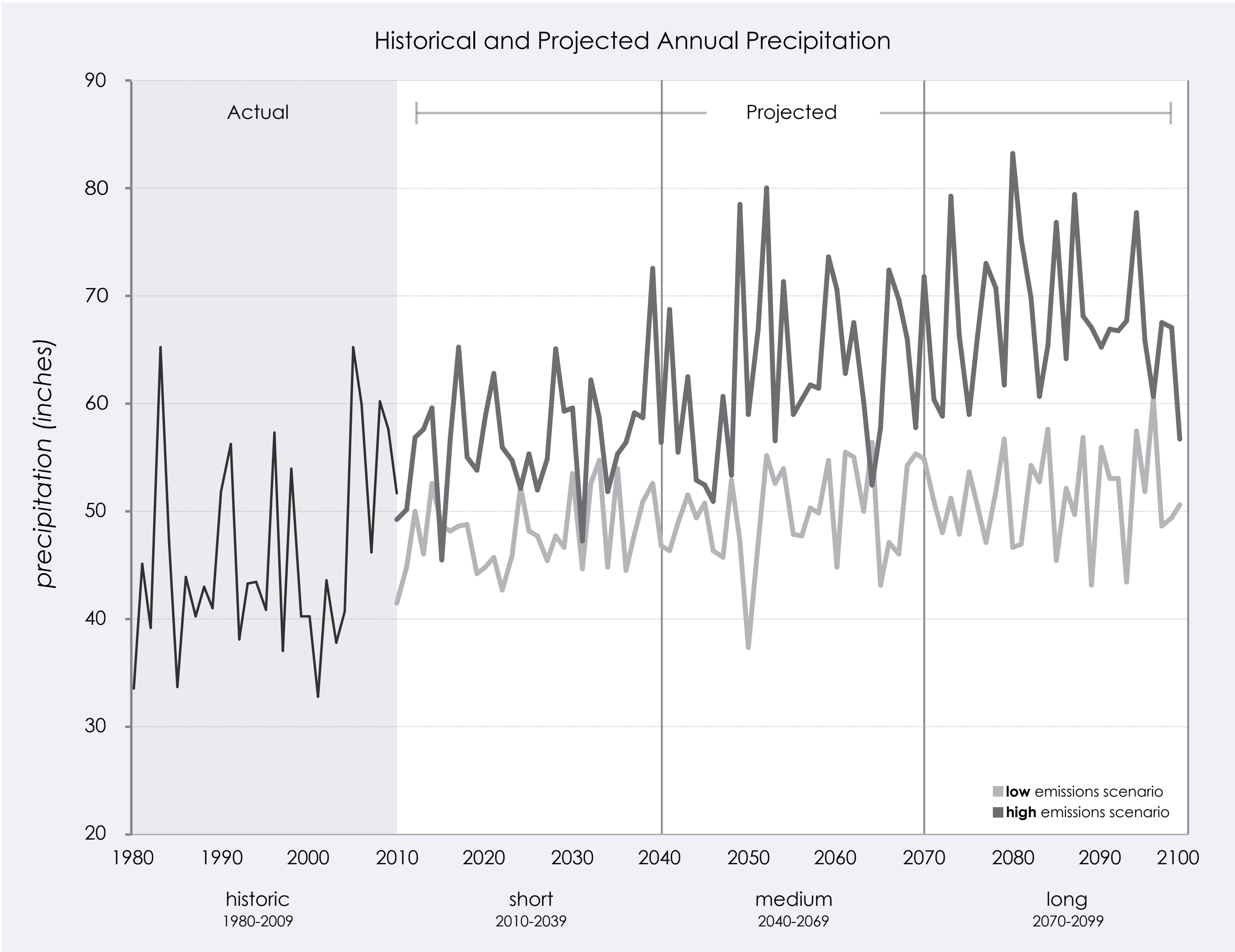


Figure 5. Historical and Future Average Annual Precipitation Trends

Seasonal Precipitation

Seasonal precipitation projections show a more nuanced picture of average rainfall totals. The projections indicate that additional precipitation will occur in the winter, while summers will become slightly drier. Historic baselines for precipitation in both winter and summer are quite similar, at 10.2 and 10.5 inches, respectively. However, by the end of the century (2070-2099) winter precipitation is predicted to rise to between 12.7 and 13.7 inches, varying between the low and high emissions scenario, respectively. This may translate into a nearly 35% increase in winter precipitation (Figure 7a). Projections indicate a decrease in summer precipitation by the end of the century, although the trend is inconsistent over the short, medium, and long term (Figure 7b). By the end of the century, summers in Wells may see as little as 9 inches of precipitation under the low emissions scenario[2].

2 In the case of seasonal precipitation, the low emissions scenario shows a more pronounced change over the long term than the high emissions scenario.

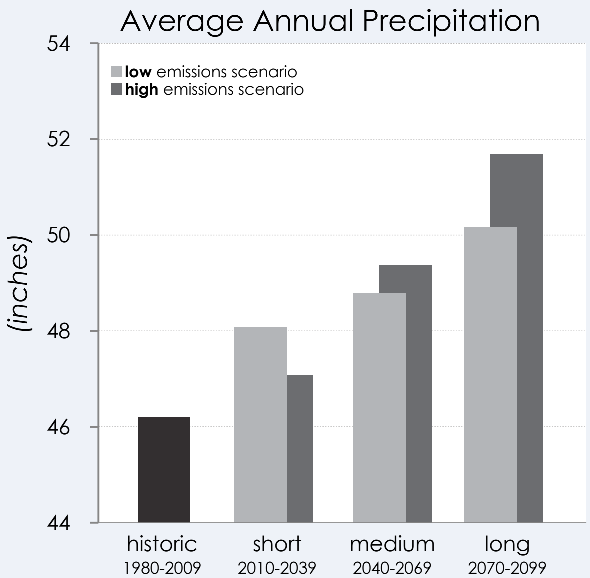
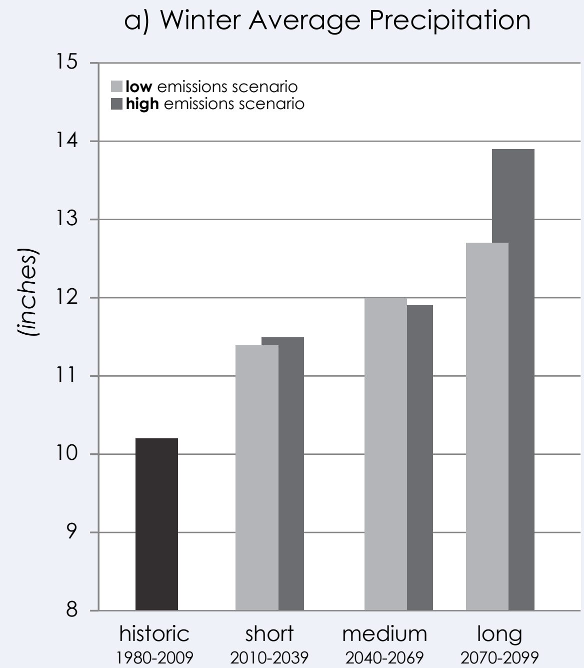


Figure 6. Short, Medium, and Long Term Annual Precipitation Trends



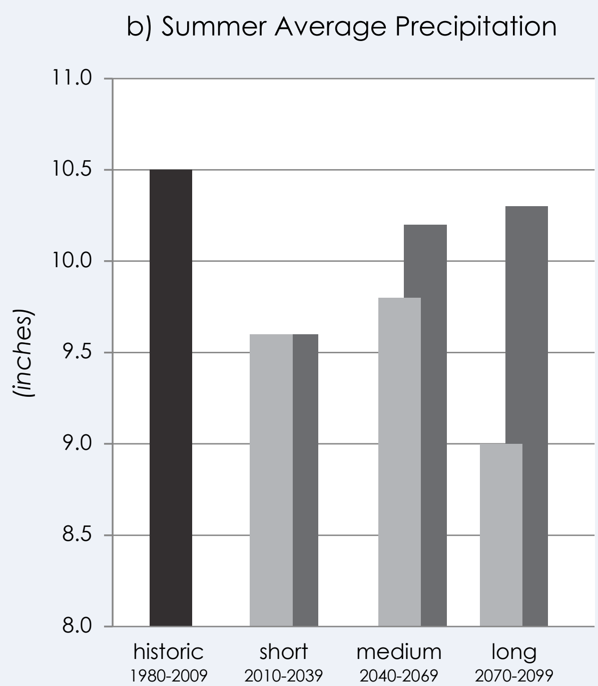


Figure 7. Seasonal Precipitation Pattern

Extreme Precipitation Events

Extreme precipitation events are characterized by the amount of rain that falls within a 24-hour or 48-hour period. These events are strongly correlated to flooding, as the precipitation comes all at once with reduced time for infiltration. Wells is projected to see more extreme precipitation events in the future, especially under the high emissions scenario. The most dramatic change is a projected doubling in the annual number of events characterized by 2 inches of precipitation in 48 hours under the high emissions scenario in the long term. Also significant is the increase in the annual number of events characterized by 4 inches of precipitation in 48 hours, which could increase from a historical baseline of 9 events per decade to upwards of 12 to 14 events, for the low and high emissions scenarios, respectively (Figure 8c). To provide perspective, the Mother's Day and Patriots' Day Storms dumped 16 inches and 8.5 inches of rain, respectively (USGS, 2009).

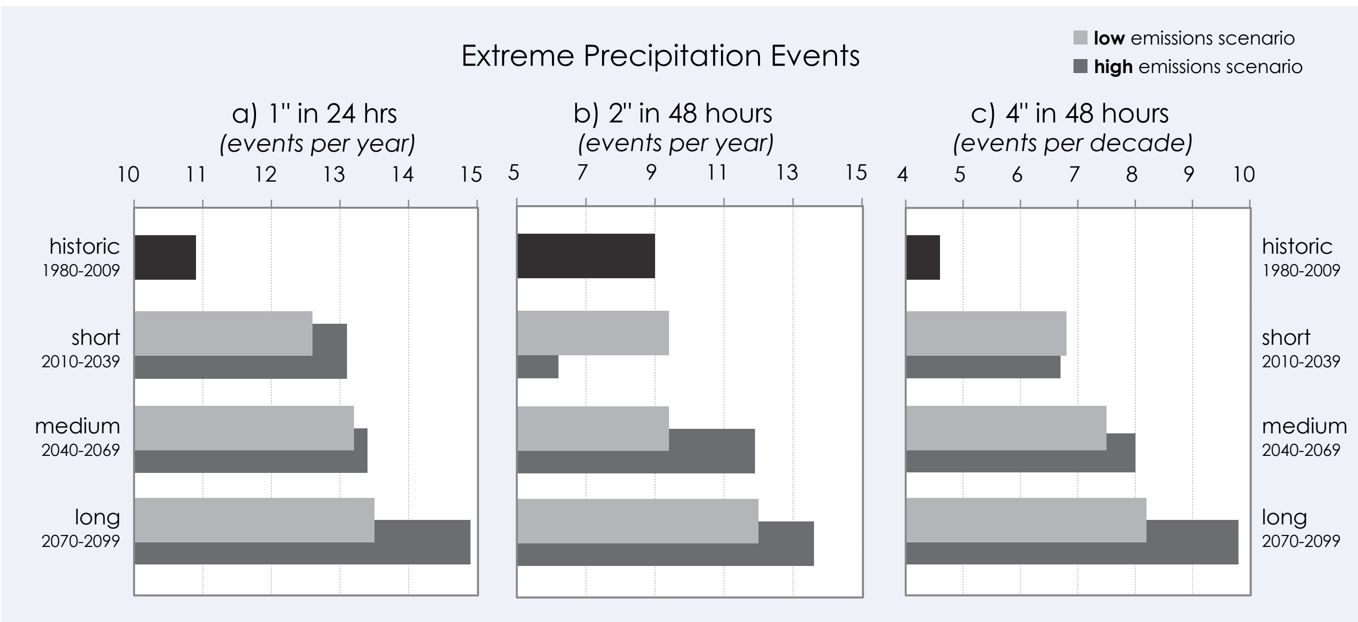


Figure 8. Extreme Precipitation Events

Table 2. Potential Impacts of Precipitation Changes

Change	Potential Impacts of Precipitation Changes
↑	**Flooding:** One of the key impacts associated with higher precipitation and more extreme precipitation events is increased flooding risk, which can potentially damage houses, businesses, and infrastructure and disrupt livelihoods.
↑	**Erosion:** Flash flooding and storm surges associated with extreme precipitation events may lead to increased erosion, especially along steep slopes and non-vegetated soil.
↓	**Water quality:** Increased stormwater runoff associated with precipitation events could increase the concentration of water-borne pollutants in urban streams.
↑	**Vector borne disease:** An increase in the amount and duration of standing water may lead to an increase in pests and vector borne diseases such as West Nile Virus.

Sea Level Rise

In the long term, Wells' sea level is projected to rise by up to 5 to 6 additional feet from levels in the year 2000 under the high emissions scenario. Sea level rise will likely have the largest impact on community assets already threatened by high daily tide levels and groundwater levels, as well as those already experiencing storm-related flooding and erosion. The high emissions scenario projects a little more than twice as much sea level rise as the low emissions scenario in the long term. Sea level projections from both high and low emissions scenarios reflect a doubling of water levels when comparing the short to medium term time frames, as well as the medium to long term time frames (Figure 9).

Table 3. Potential Impacts of Sea Level Rise

Change	Potential Impacts of Sea Level Rise
↑	**Daily tidal inundation:** Sea level rise will likely increase the extent of daily tidal inundation with social, economic, and ecological implications.
↑	**Coastal Flooding:** Coastal flooding risk will increase due to sea level rise, especially when coupled with increases in extreme precipitation events and possible increases in hurricane intensity.
↑	**Groundwater levels:** Rising groundwater levels may damage infrastructure and property along the coast.

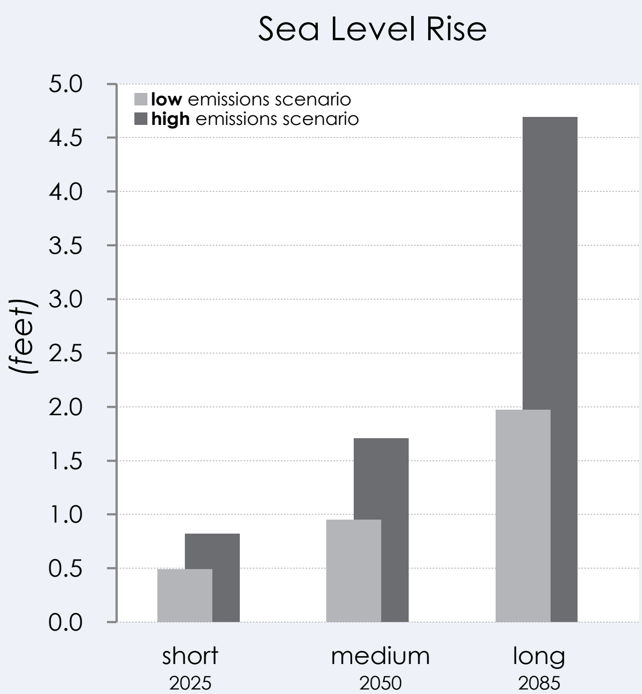


Figure 9. Sea Level Rise Projections

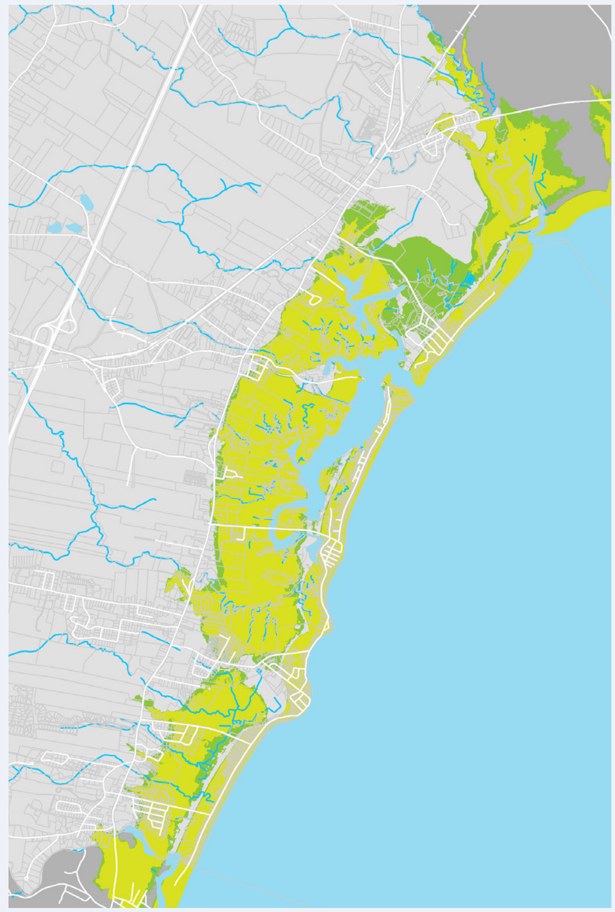


Figure 10. Coastal Sea Level Rise. Mean Sea Level Inundation

High emissions scenario - *medium term (2050)*
High emissions scenario - *long term (2085)*
(additional area flooded)

Section 2: Integrated Risks and Adaptation Options

This section of the report builds on the climate change projections and possible impacts from Section 1, and applies them to community systems and assets in the Town of Wells to examine some of its key climate change risks, vulnerabilities, and adaptation options. Figure 11 represents the approach we used to understand and assess risk. This approach is based on the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Extreme Events (IPCC, 2012). Risk (white circle) is the likelihood of impact resulting from the interaction of:

- a **threat,** an event caused by natural variability and/or anthropogenic climate change, and
- **vulnerability,** the sensitivity, exposure, and adaptive capacity of a place and its likelihood to be adversely affected.

Climate adaptation refers to efforts focused on reducing local and regional vulnerability and increasing resilience to climatic risks. Adaptation options (right side of the diagram) reflect alternative mechanisms that can be used to reduce Wells' risk to a given climatic threat through minimizing exposure (e.g. moving out of harm's way), reducing sensitivity (e.g. storm-resistant building techniques), and increasing adaptive capacity (e.g. wide buffers). Adaptation options can be broadly grouped under four categories: 1) no action, 2) accommodation, 3) protection, and 4) retreat. The type of adaptation option that is appropriate in a given situation and time will depend on a number of factors, including, but not limited to, the magnitude of the threat, the timeframe and probability of the threat, the associated economic, social, and ecological cost of the risk, and the availability of resources and knowledge at the time. Accommodation

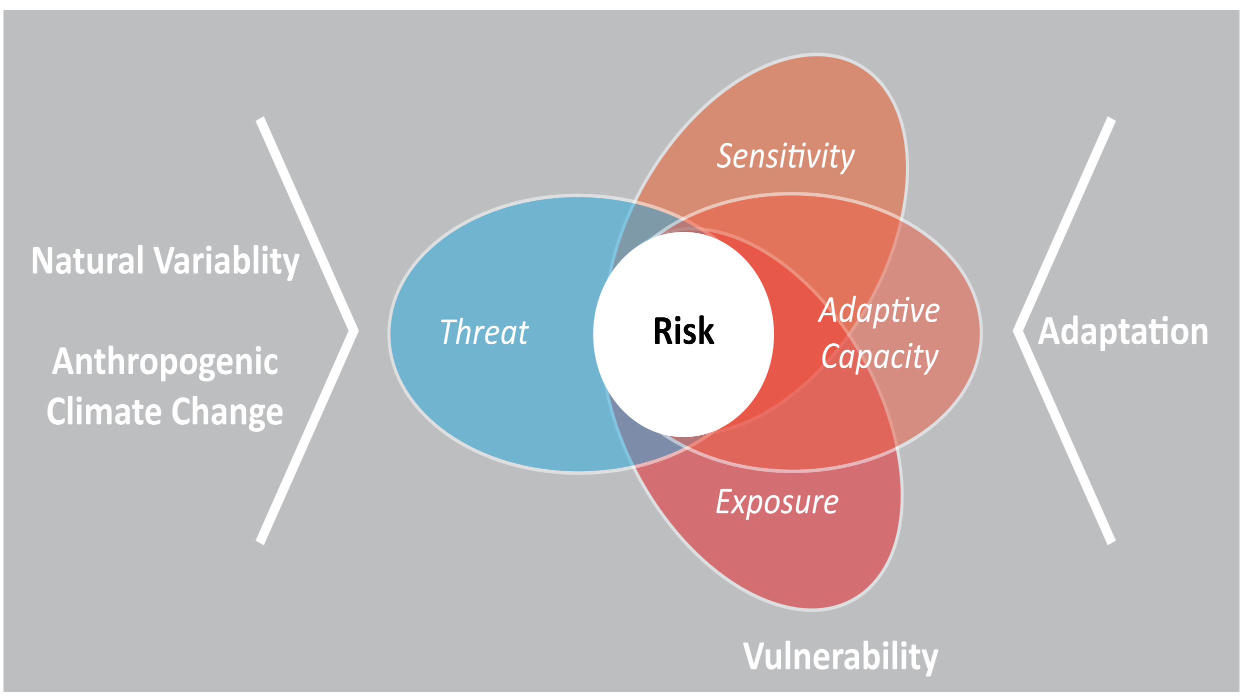


Figure 11. Integrated Risks (Adapted from IPCC SREX Report)

options focus on increasing preparedness and reducing sensitivity in case a threat occurs. These approaches may include early warning systems, the modification of ground floors of buildings to decrease flooding damages, and/or removal of critical infrastructure from ground floors. Protection options seek to reduce risk through preventing a threat from occurring. These measures could include things such as repairing seawalls and restoring or creating wetlands to prevent flooding. Lastly, retreat options reduce exposure by moving the population away from the threat, such as through relocation, setback requirements, and phasing out development in high-risk areas. In contrast to climate change adaptation, climate change mitigation practices that reduce global greenhouse gas emissions aim to lessen the speed and severity with which regional climates are changing and, as a result, minimize climate change risks globally and in the long term.

This section highlights several risks including ***flooding***, ***heat waves and rising temperatures***, ***tourism and fiscal diversity***, ***drought*** and ***marine habitat health***. Specific vulnerabilities for Wells were identified through consultation with key individuals from the town and climate change experts, as well as through the review of published documents, including the 2011 New England Great Bay Report and the 2009 Maine's Climate Future Assessment. See Additional Resources in Appendix 2 for more in-depth narratives and diverse examples of adaptation options.

Flooding

Risks

Wells is already vulnerable to river and coastal flooding[3], and the risk of flooding will likely increase with additional climatic changes that lead to more extreme precipitation events, warmer winter temperatures resulting in precipitation falling as rain instead of snow, sea level rise, and higher storm surges during extreme precipitation events. Wells is also vulnerable to flooding associated with stormwater runoff.

Coastal Flooding. Coastal flooding is a major threat for Wells due to the region's shallow and developed coastline. The majority of the 2008 Federal Emergency Management Agency's (FEMA) 100-year floodplain for Wells is characterized by coastal, rather than riverine, flooding (Figure 12). Coastal flooding will almost certainly increase in the future due to sea level rise, which is caused primarily by the thermal expansion of seawater, melting of ice on land, and glacial melt occurring as a result of increasing air temperatures around the globe. Future sea level rise will increase the average high tide elevation, as well as lead to higher storm surges. Based on climate projections for the high emissions scenario, over 4,000 acres will be inundated on a daily basis by the end of the century due to rising sea levels (Figure 13). The area inundated by future sea levels expands beyond the current federally designated floodplain. In other words, in the future, it is projected that the area currently designated as having a high flood risk will be underwater on a daily basis.

Sea level rise will shift the tidal level such that the capacity of stream channels to take on water during storms will be reduced and the height of storm surges will rise. As a result, Wells may see a greater extent of flooding associated with hurricanes and other severe storms. This could mean that, in the future, a category 1 hurricane might inundate an area similar to the area that a category 3 hurricane would currently flood (Figure 14) as there are only ~2 feet in difference between the maximum elevations of category 1 and 3. While sea level is expected to rise between 2 to 5 feet over the long term.

River Flooding. In addition to coastal flooding, Wells may see increased flooding along its rivers and streams. The floodplain is delineated based on the probability of flooding in a given year. Figure 15 shows both the current 100-year floodplain (i.e., an area with a 1% chance of flooding in given year) and the 500-year floodplain (i.e. an area with a 0.2% chance of flooding in a given year). The current 100-year floodplain in Wells covers an area of 4,600 acres while the 500-year floodplain adds an additional 520 acres. FEMA is currently in the process of updating the 100- and 500-year floodplain maps for the Town of Wells. These map updates will predominately reflect changes in flood risk due to changes in land cover and better elevation data (Fernandes, 2013). Future increases in annual precipitation and frequency of extreme precipitation events will likely further increase the risk of flooding along Wells' streams. In addition, as noted above, sea level rise will reduce the capacity of coastal streams to take on water during storm events, which means they will overflow their banks under lower precipitation conditions than they did in the past.

3 Recent floods include the Patriots' Day Storm of 2007 and the Mother's Day Storm of 2006.

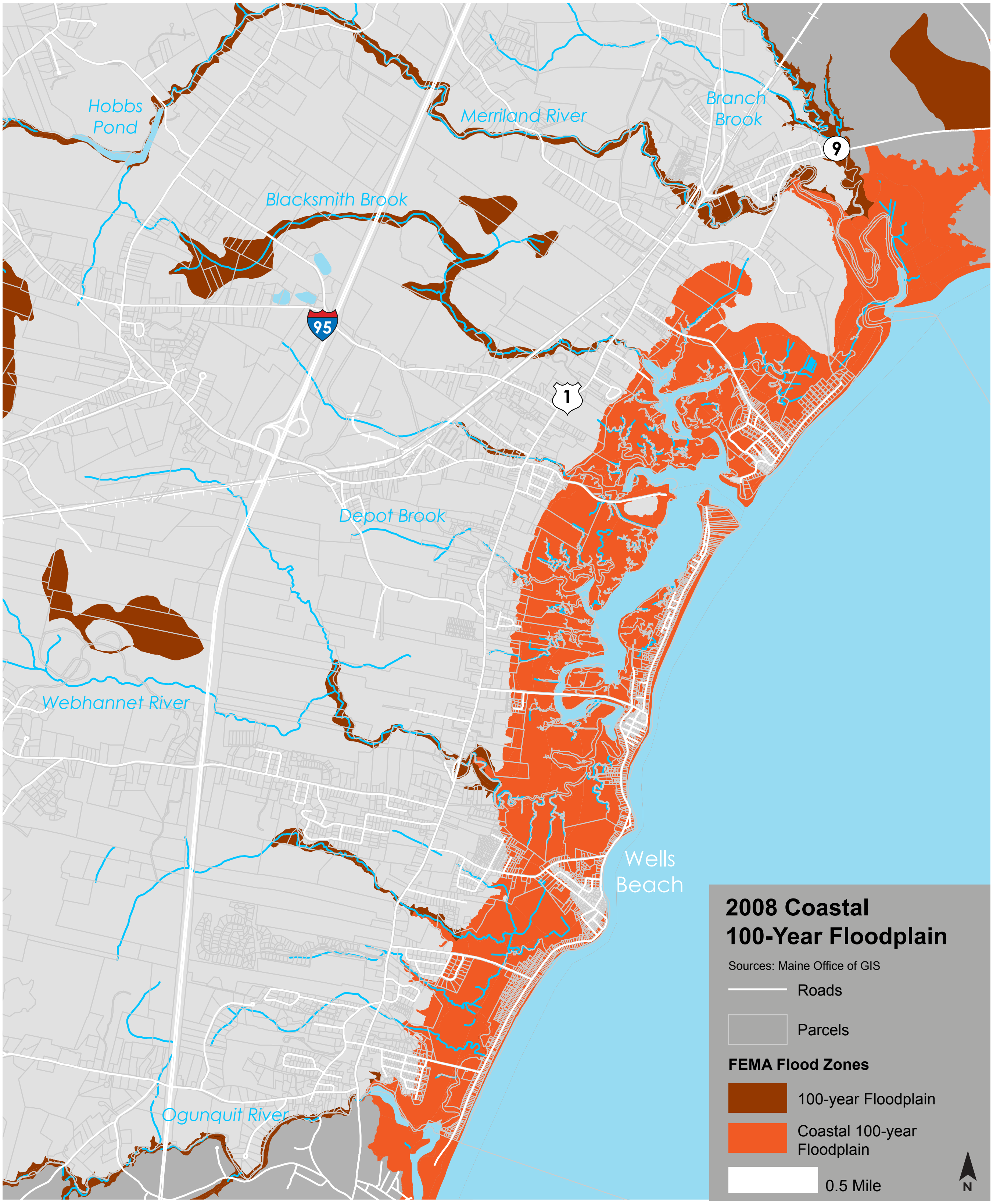


Figure 12. Coastal 100 Year Floodplain

This map was generated using publicly available spatial data from state and county GIS departments. Sea level rise is relative to NAVD88 at the nearest tide station (Fort Point, NH). This includes LiDAR data, administrative boundaries, and natural features. After conversion to the appropriate vertical datum (NAVD88), simple geoprocessing tools were used to reclass the elevation data and add sea level rise.

More sophisticated techniques – for instance the SLOSH model – require better quality data regarding storm surge heights and winds resulting from historical or predicted hurricanes, as well as engineering considerations such as infrastructure and unique bay and river configuration. As such, the maps in this assessment are intended for visualization purposes only.

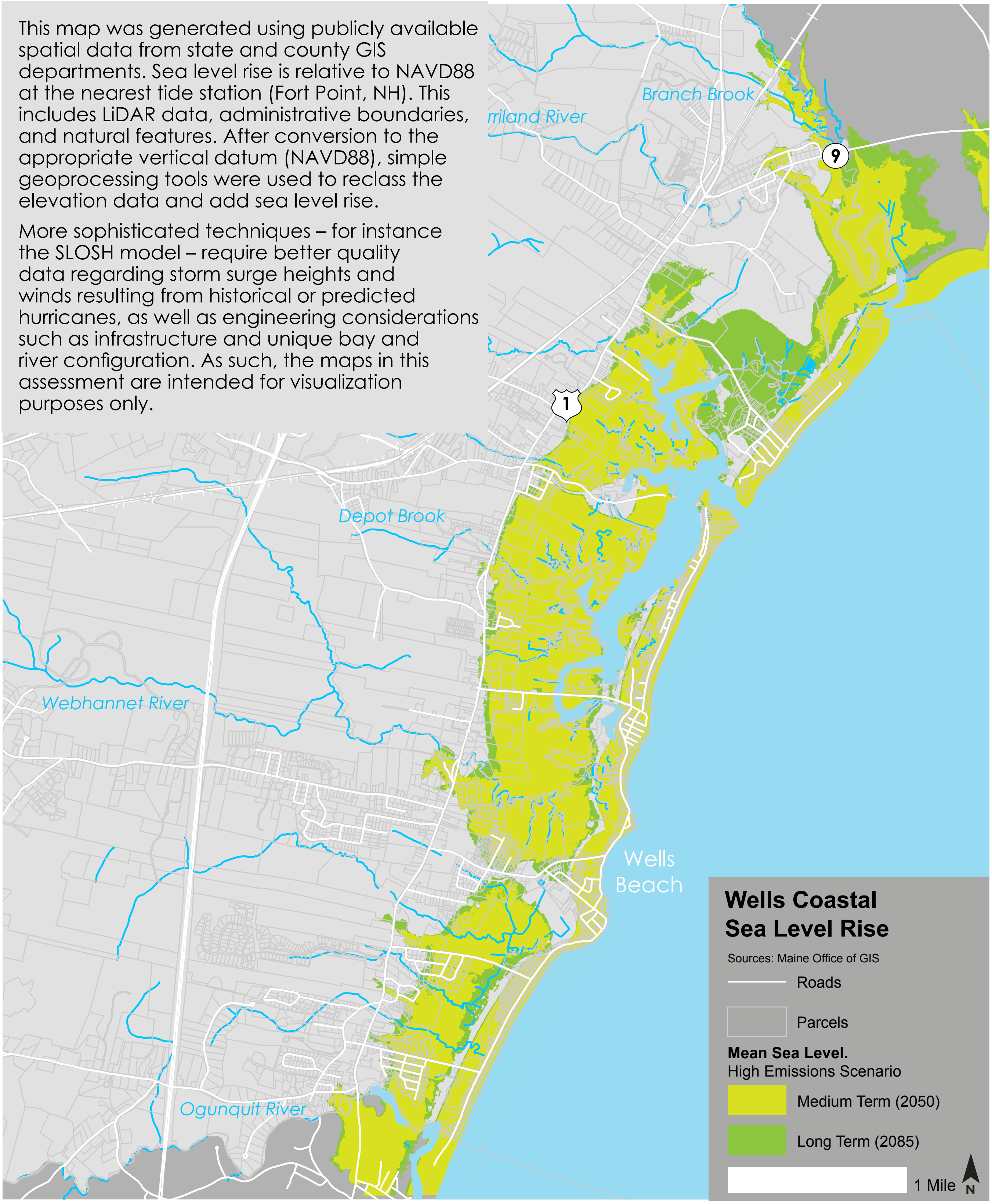


Figure 13. Average Tidal Inundation under Future Sea Level Rise along Wells' Coastline

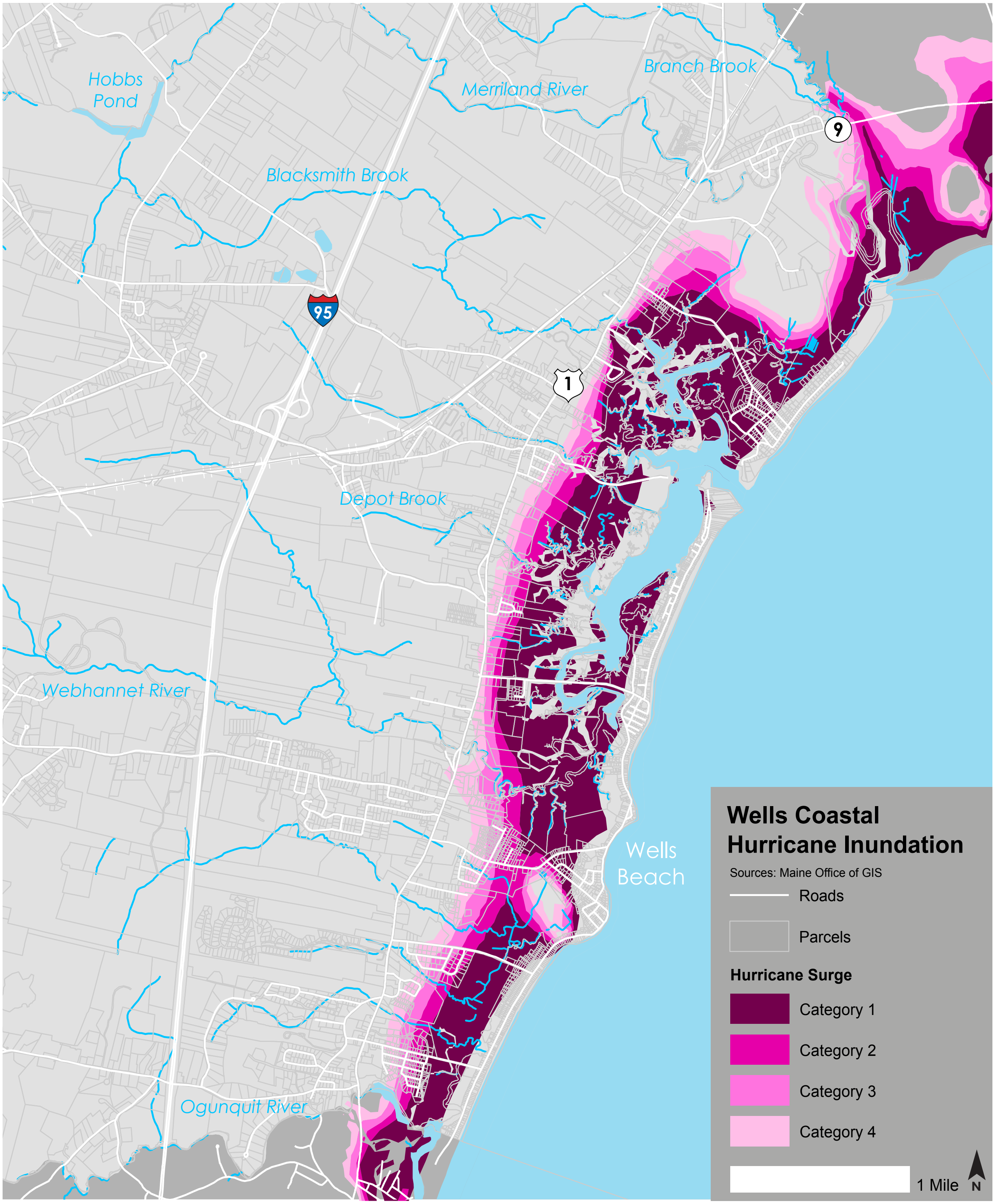


Figure 14. Current Hurricane Surge

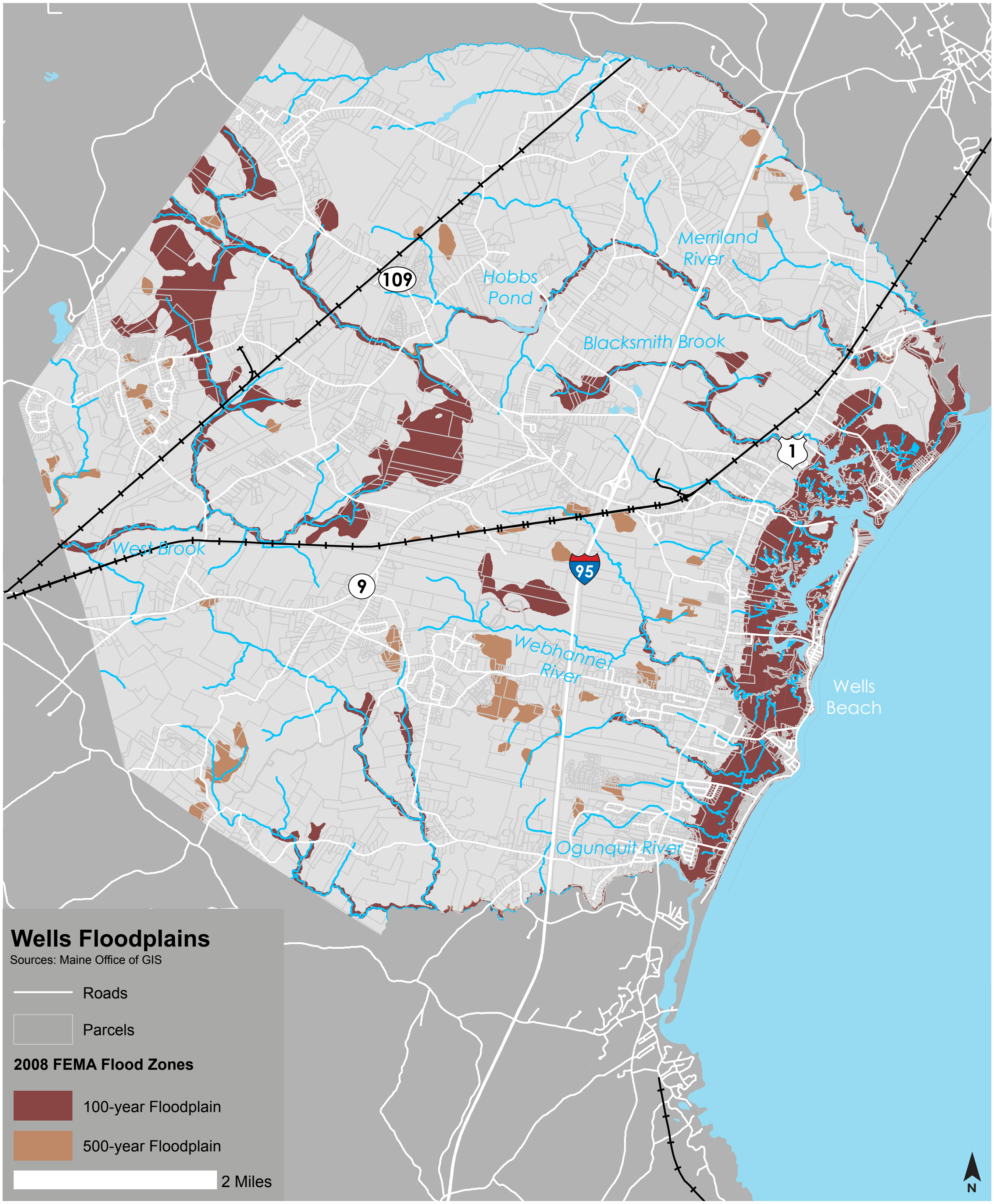


Figure 15. Wells' 100 and 500 Year Floodplains

Figure 16. Street Flooding

Figure 17. 2010 Storm at the Wells Reserve

Stormwater Runoff

The increase in frequency of extreme precipitation events is expected to increase the risks associated with stormwater runoff. In developed landscapes, stormwater runoff flows quickly off of impermeable and hard surfaces into drainage ditches, streams, and culverts. This large load of water picks up sediment and debris along its path, and can erode stream banks and wash out roads, as was the case during the recent Mother's Day and Patriots' Day storms (Figure 16). Due to Wells' small size, it is not regulated under EPA's MS4 (Municipal Separate Storm Sewer System). However, Wells is undertaking best management practices to deal with stormwater runoff challenges. Low impact development methods such as biofiltration, green infrastructure, and natural buffers are already part of Wells' regulatory, permitting, and design processes. However, these practices focus on water quality issues more than flooding.

Vulnerabilities

Neighborhoods and Properties. The areas of Wells that are most vulnerable to sea level rise include the neighborhoods of Wells Beach, Moody Beach, Drakes Island, and Wells Harbor. Sea level rise could also affect interior waterways, such as the Little River. Based on climate projections, over 1,900 parcels will be in moderate to high risk of flooding over the long term within the town of Wells . In the future, properties in the current flood hazard area will be at greater risk of flooding, since the frequency of flooding is predicted to rise. Buildings can be severely damaged by floodwaters, causing displacement of residents and businesses. Basements can become damaged from higher groundwater levels and leaks associated with flood events. Flooding may also cause residences and businesses to lose power and water service, and road closures caused by flooding can prevent access to homes, businesses, and services, such as hospitals and schools.

Infrastructure and Transportation Networks. Flooding can temporarily block or impede the function of infrastructure, as well as lead to costly repairs. Transportation networks can be blocked by floodwaters, closing off evacuation routes. For example, the community of Drakes Island is entirely within the 100-year floodplain and may need to be evacuated during a flood emergency. Comparing the road network to the flood risk layers, it appears that coastal routes such as Atlantic Ave and Ocean Ave as well as inland roads including State Highway 9, Quarry Road and Bragdon Road may be impaired in a flood emergency. Amtrack's rail line may be inundated in the future where it crosses the Merriland River and Blacksmith Brook (Figure 18). During the large storm events of recent years, Wells experienced damage to its public infrastructure including culverts, roads and bridges, and the seawall. These structures are being replaced with larger storm capacities to accommodate future impacts.

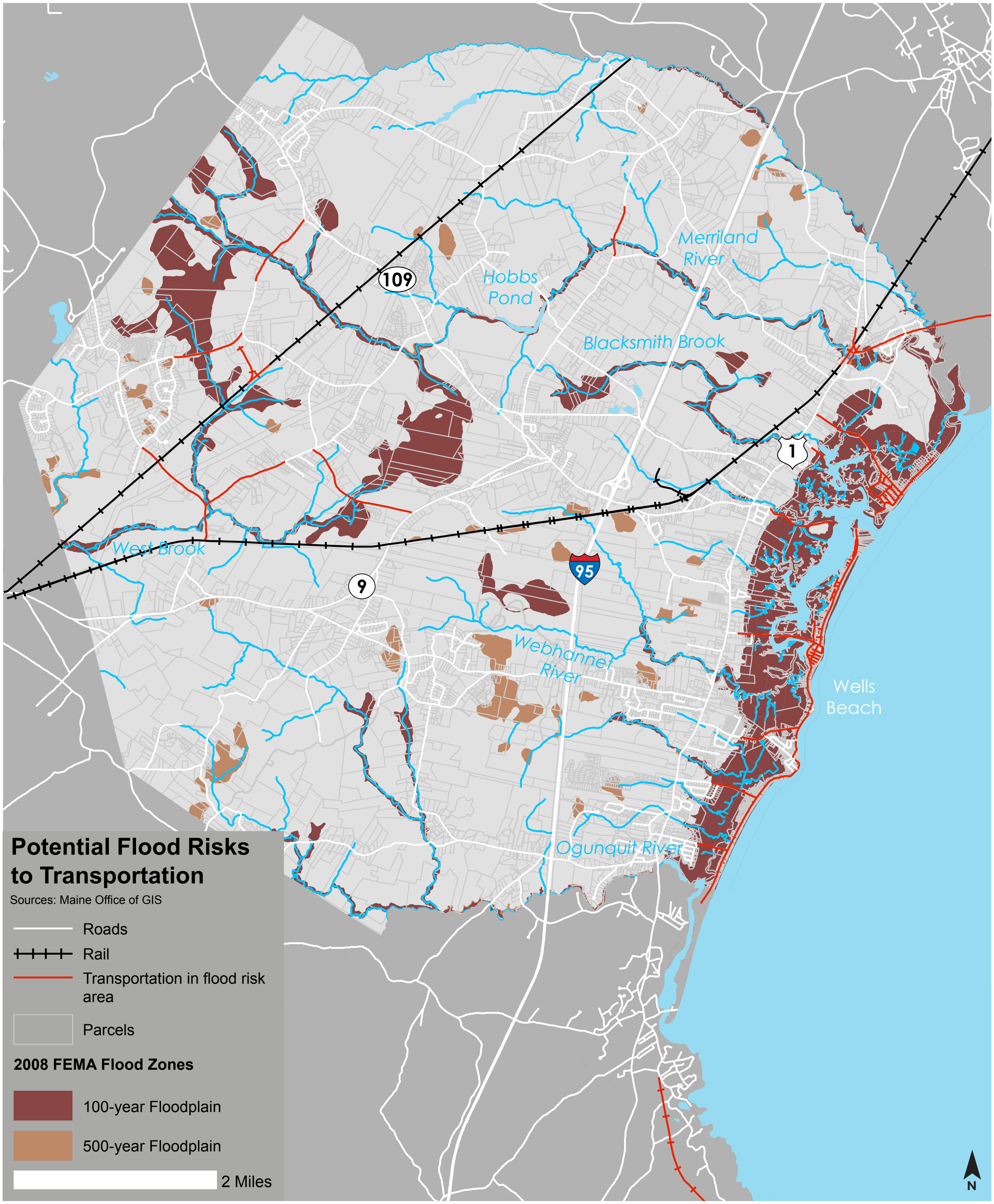


Figure 18. Potential Flood Risks to Transportation

Social Vulnerabilities. Displacement caused by flooding is a major social vulnerability. Populations with lower mobility, due to both physical and economic reasons, may be more sensitive to flood impacts. Sensitive populations (such as the elderly, very young, and presently ill) have lower physical mobility rates and are therefore at risk from major hazards. However, there are no nursing homes or hospitals within the Town of Wells. Lower income households may have limited savings and can be especially hard hit by the disruption of work and expenses of recovery associated with flooding. According to the 2010 US Census, fewer than 5% of households in Wells are below the poverty level.

Ecosystem Changes. Barrier beach and interior marsh ecosystems provide valuable flood protection for nearby properties as well as other important ecosystem services. However, they are also highly susceptible to negative effects from coastal flooding, and are highly vulnerable to sea level rise (SeaGrant). By the end of the century, sea level rise is projected to fully submerge the Wells Reserve estuarine lands (Figure 20). In the shorter term, it is unclear whether Wells' marshes will have room to migrate upland, and whether they will be able to migrate quickly enough.

Beach erosion is caused by sea level rise and increased intensity of storms. Wells has already experienced beach erosion, but climate change will increase the rate of erosion as the sea level rises and extreme precipitation events become more common. Beach erosion can be a threat to coastal properties. It also may have negative economic impacts, since the town's tourism industry relies on Wells' beaches as a primary attraction.

Accelerated sea level rise and erosion could also threaten coastal wetlands, where diverse species including mollusks and the endangered Piping Plover find food and protection. Saltwater marshes and freshwater marshes are both vulnerable to sea level rise. Inundating the salt marshes could lead to waterlogging and plant death (Figure 21). Further, salt marshes provide important functions to coastal zones as they reduce wave actions during storms (Mudd, 2011).

Increased stormwater runoff has been associated with damage to riparian and estuary habitat. Rainfall can carry nutrients and pollutants into rivers and estuaries, leading to water quality issues and negatively affecting river and coastal ecosystems. While downriver wetlands are natural filtering stations, declining marshes due to sea level rise combined with heavier storms and upstream development could lead to significantly impaired waterways in the future. Water quality impacts could negatively increase bacteria counts, leading to beach shutdowns and detrimentally affecting surrounding ecosystems. While in the past beach closures have occurred infrequently, Wells' economic reliance on tourism makes closures one of the town's highest concerns (Livingston, 2014).

Figure 19. 2010 Storm Damage

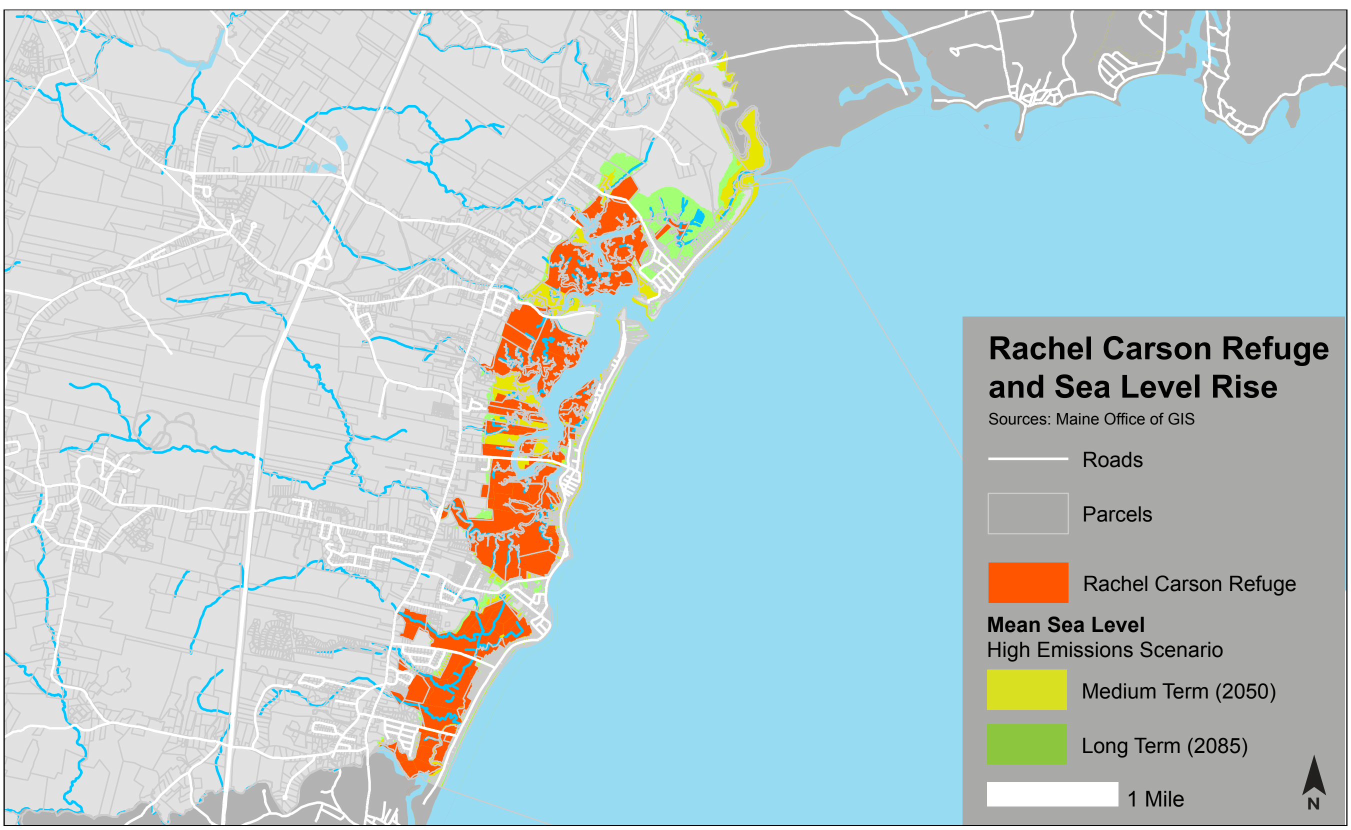


Figure 20. Rachel Carson Refuge and Sea Level Rise Scenario

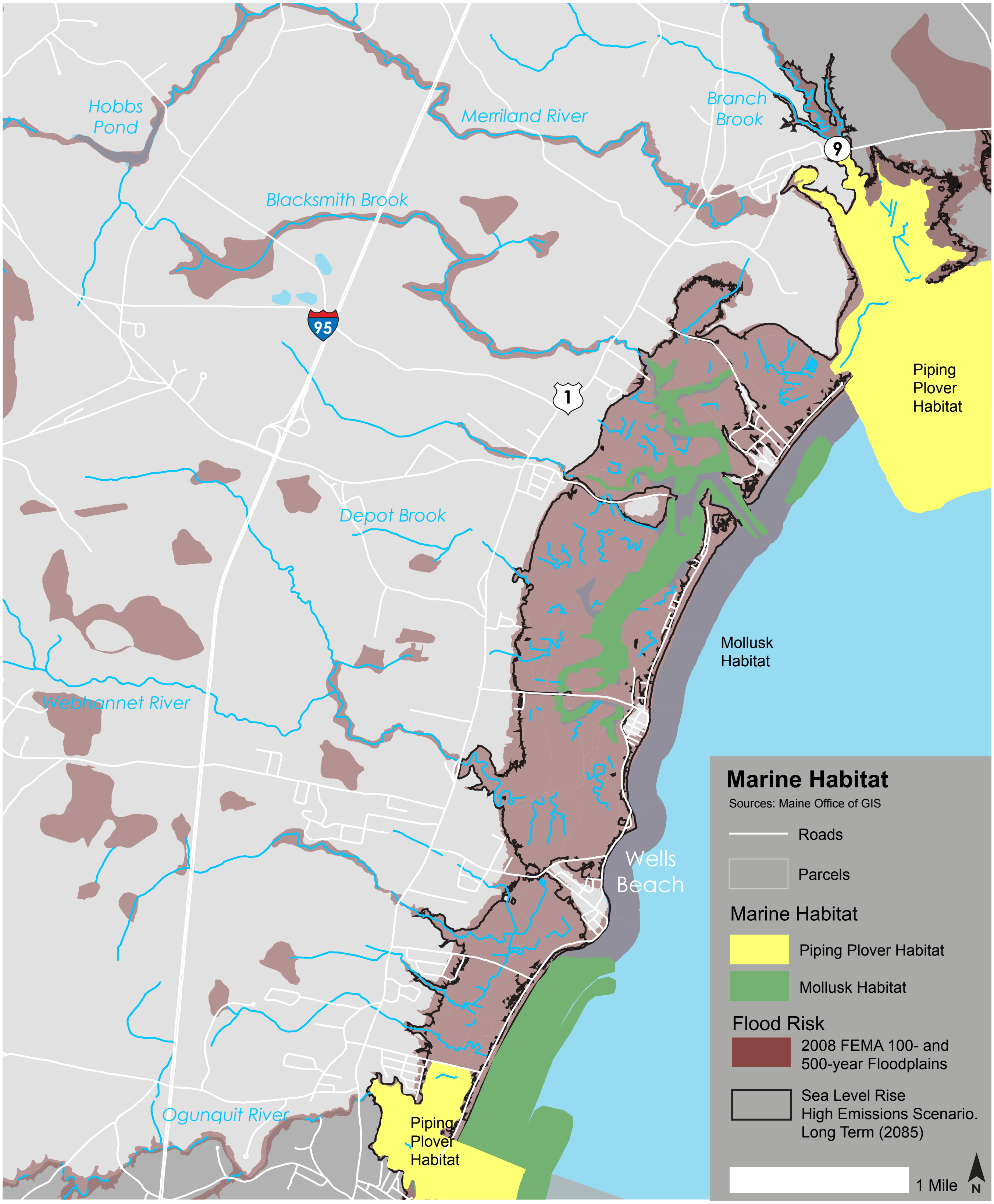


Figure 21. Marine Areas

Adaptation Options

There are a wide variety of adaptation options that can be undertaken to reduce Wells' sensitivity to flooding (such as flood-proofing houses) and to reduce the town's exposure to flooding (such as moving communities out of the flood zone). While some communities employ protective structures (for example seawalls and levees) these are not legal in Maine. Alternative adaptation options aimed at reducing individual property and community flood risks are included in Table 4a. Table 4b focuses on minimizing flood risks to infrastructure. Lastly, Table 4c focuses on reducing flood impacts on ecosystems. During the stakeholder interview process several stakeholders emphasized the importance of education for youth and adults about climate change adaptation. Local organizations, such as the Wells Reserve at Laudholm, Maine Sea Grant, and others, have been active in this effort.

Table 4. Adaptation Options for Flooding

a. Adaptation Options to Reduce Community and Property Flood Risks
Flood-proofing: Raise homes and other structures above the 100-foot floodplain elevation.
Insurance: Flood insurance and other forms of financial security can help people rebuild after a climate-related disaster.
Emergency services: The Fire Department, Police Department, and Emegency Management Department continue to play a critical response role in emergency relief. Succesful efforts employ various strategies that are coordinated in time and location. There is an opportunity for greater collaboration between adjacent municipalities on services like water infrastructure or emergency management, rather than duplicating efforts.
Protect and restore dune systems: Replenish sand in beaches and protect dune systems from development and further erosion. Replenishing sand is considered a short-term strategy as it requires constant maintenance.
Planning and zoning approaches: Limit future development in flood-prone areas and/or incentivize development in less flood-prone areas.
Buy-backs: Implement a voluntary building buy-back program to help residents move out of the floodplain. Cranston, Rhode Island is doing this on a pilot basis, and a number of cities in New York and New Jersey are offering buy-back programs as part of their post-Sandy reconstruction toolkit.

b. Adaptation Options to Reduce Infrastructure Flood Risks

Retrofit: Raise and fortify emergency routes between the coast and the inland town. Culverts can be upgraded to handle larger amounts of runoff during storms.

Gray and green infrastructure: Reduce stormwater runoff by implementing "green" solutions (e.g. low-impact development regulations) or "gray" solutions (e.g. bigger sewage pipes and storage tanks). This may be helpful in developed areas and areas susceptible to riverine floods, but it will not reduce flooding due to storm surges or sea level rise.

Redundant systems: Invest in alternative systems that complement rather than replace current infrastructure. For example, support a multi-modal transportation system or multiple evacuation routes in case one route fails.

c. Adaptation Options to Reduce Environmental Impacts from Flood Risks

Addressing beach erosion: Possible short-term adaptation steps to combat beach erosion could include: sand replenishment, geotubes to shore up beaches, and dune restoration and vegetation, which would be more durable than dumping sand alone. Unfortunately, all of these options are temporary solutions. As sea level rises and storms become more intense, erosion and/or migration of Wells' beaches may be unpreventable.

Addressing marsh habitat: Acquire lands adjacent to marshes to facilitate marsh migration and remove barriers to marsh migration, such as roads, floodwalls, or armoring. Keep marshes healthy by minimizing pollution and damage in order to make them as resilient as possible, which will increase their chances of being able to adapt to changing conditions. Although these measures may help, marshes may not be able to migrate quickly enough to keep up with sea level rise.

Addressing stormwater runoff: Implement "green infrastructure" approaches, such as greenroofs and rain gardens. Green infrastructure can both slow down runoff and reduce pollution loads through biofiltration. It can also be implemented incrementally and, unlike most traditional infrastructure, actually increases in effectiveness over time. For instance, a 20-year-old tree can absorb a lot more water than a 5-year-old tree. Putting in place green infrastructure may also help Wells to increase the adaptive capacity of its species and habitats by supporting wider ecological buffers and providing extensive habitat corridors and more interior habitat. While green infrastructure has many benefits, it is important to recognize that, as the magnitude of flooding increases, the capacity of green infrastructure may be overwhelmed.

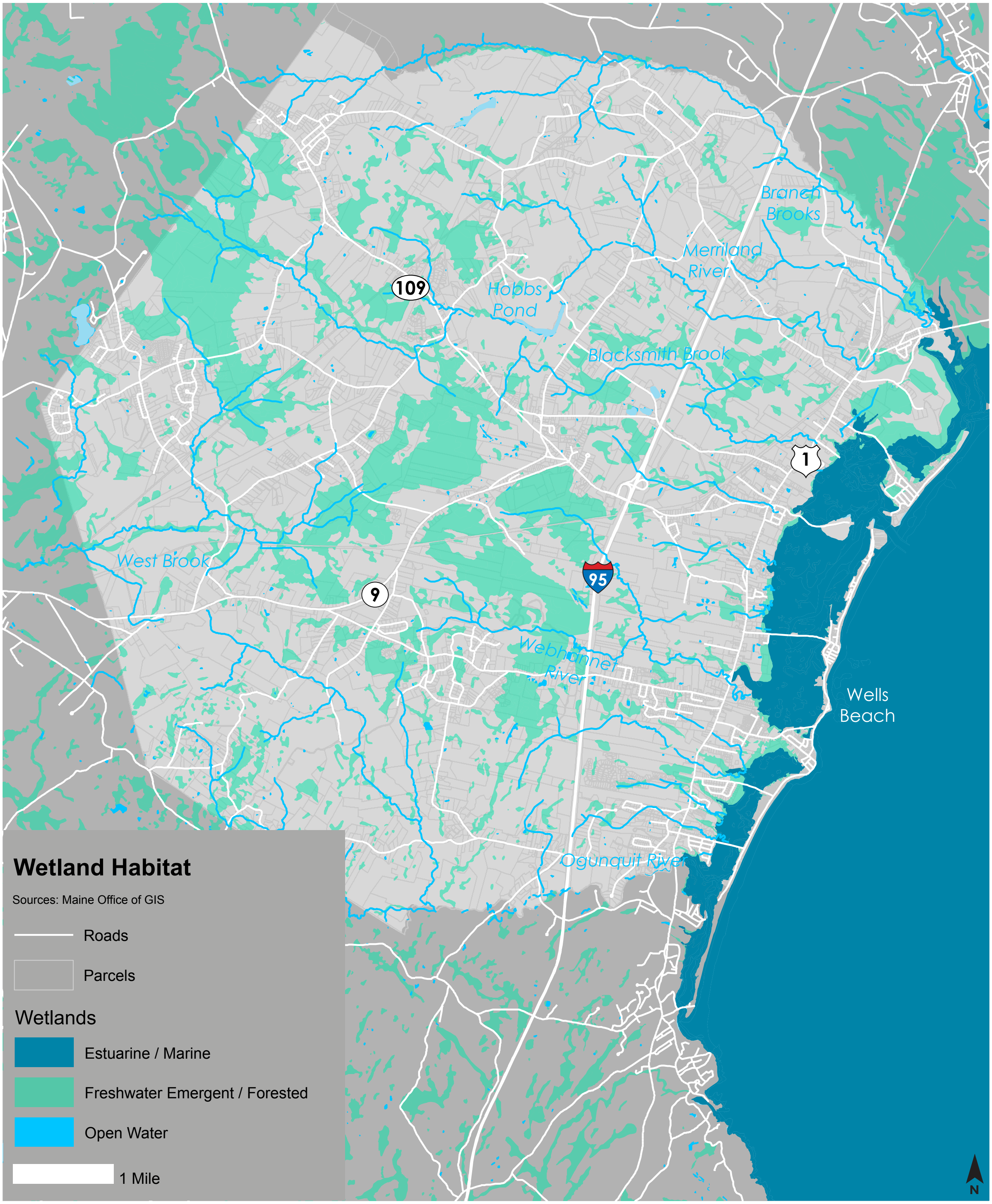


Figure 22. Wetland Habitat

a) Restored Wetland

b) Sand Replenishment

c) Buy-backs

d) Pervious Pavement

e) Flood Resilient Building

f) Low Impact Development

Figure 23. Flood Adaptation Options

Heat Waves and Warmer Temperatures

Risks

Heat waves are driven by extreme heat events, which are projected to occur up to 9 times as often by the end of the century. Heat waves are particularly dangerous for human health and infrastructure when they last for long periods of time, when evenings do not cool down, and when heat is coupled with high humidity.

Vulnerabilities

Public Health. Maine residents may be vulnerable to heat-related health impacts because many homes do not currently have air conditioning. The elderly, children, low-income residents, and those who work outside are especially susceptible. Higher temperatures can also contribute to more air pollution, which disproportionately affects the health of the young and elderly.

Increased temperatures may increase exposure to disease vectors that are more common in warmer climates, such as Lyme disease-bearing ticks and West Nile-bearing mosquitos. Residents may need to be educated about new disease vectors and pests that are not currently common in the area, in order to prevent unnecessary exposure.

Electricity Infrastructure. Extremely high temperatures can cause electrical wires to sag and come into contact with trees or structures. Prolonged heatwaves can also damage other electricity distribution equipment, such as transformers, which are designed to cool down during the evenings. Additionally, peak electricity demand tends to occur during hot summer afternoons and increased demand due to hotter days has the potential to cause reliability problems, such as brownouts or blackouts, if electricity demand outstrips supply.

Adaptation Options

Reduce Exposure and Sensitivity of Vulnerable Populations. An option for reducing the health impacts of heatwaves is to reduce the exposure of vulnerable populations. Strategies include providing cooling centers during heatwaves, retrofitting substandard housing, and providing assistance for people who cannot afford their electricity bills. Planting shade trees can function as a long term strategy to reduce residential air conditioning use.

Reduce Vulnerability of Electricity Infrastructure. Options for reducing the vulnerability of electrical infrastructure to heat waves include improving the equipment and implementing energy efficiency measures that reduce stress on the electricity system during heat waves. Many electric utilities employ innovative demand management techniques, including programs that compensate customers who agree to have the electrical supply for certain devices (such as irrigation pumps or air conditioners) cycled on and off during periods of peak demand to reduce overall energy use. Some large industrial utility customers can even agree to run their operations at night, which reduces the load on the system during daytime peaks. General energy efficiency policies and practices also serve to lower average energy

a) Building Retrofits b) Cooling Center c) Shade Trees

Figure 24. Adaptation Options for Heat Waves

demand. Distributing and diversifying electricity sources is another way to improve electrical system reliability during extreme weather events. This could involve backup generation options, electricity storage options, and on-site energy options, such as rooftop solar power. Finally, maintaining and updating aging distribution infrastructure, such as transmission lines and transformers, is important for preventing system failures during heat waves (Vine, 2011).

Tourism and Fiscal Diversity

Risks

Tourism is one of the primary sources of economic activity in Wells. Summer residents and short-term visitors come to Wells to stay in coastal properties and enjoy the area's beaches and natural amenities. In addition, a large percentage of Wells' tax base comes from coastal properties. The fiscal wellbeing of Wells is therefore largely dependent on the safety and access to those properties. In light of Wells' reliance on tourism and coastal property values, climate change impacts on the town's natural and built environments have the potential to significantly affect the town financially and economically.

Vulnerabilities

Tourism. Longer summer seasons and warmer winters may extend Wells' tourist season, which could have a positive economic impact, at least in the short term. However, the potential impacts of climate change on Wells' beaches, marshes, and other natural areas may degrade their environmental quality, which would likely have negative impacts on the tourism industry. In addition, tourist infrastructure in flood-prone areas, such as along the coast, is vulnerable to sea level rise and coastal storms.

Wells' large population of summer-only residents and tourists may provide an additional challenge to Wells' adaptive capacity. Seasonal residents and visitors are less likely to have detailed local knowledge or familiarity with emergency response procedures. They also may be

less likely to implement personal resilience measures, such as having emergency supplies or a generator on-hand. Therefore, they may be a particularly vulnerable population in the event of a major storm. Further, they may be less willing to invest in collective adaptation options, such as infrastructure upgrades.

Coastal Properties. A large storm that destroys a substantial amount of coastal property could threaten the town's ability to raise tax revenue. Additionally, as the sea level rises and resultant impacts begin to manifest, such as coastal erosion and increased flood risk, coastal property values may decline, which will also negatively affect the local tax base. Abandonment of properties that are severely damaged by storms and flooding could also create liability for the town.

Adaptation Options

Potential adaptation options include diversifying the town's economy and encouraging development away from the coast, adapting tourist infrastructure to reduce its vulnerability, and protecting natural areas for their ecotourism value.

Drought

Risks

The threat of increased drought in Wells is driven by the projected decrease in summer precipitation, increase in summer temperatures, which could result in more evaporation and transpiration, and warmer winters, which could result in less snow pack. For this report, we have not included drought projections because of their high uncertainty. However, previous analysis has suggested that, in the long term, much of New England will experience a significant increase in drought. For example, short-term drought (up to one month in duration) is expected to increase two- to three-fold by the end of the century under the high emissions scenario (Hayhoe et al., 2007).

Vulnerabilities

Drinking Water Supply. The duration and frequency of drought will determine its impacts on water supply. Drought can particularly impact the potable water supply. Wells' water supply comes from wells and Branch Brook. Wells residents may be particularly vulnerable if a drought causes groundwater levels to fall, because they are not relying on water stored in reservoirs. A prolonged drought could impact Wells' surface water supply, but the vulnerability of that water supply has not been analyzed in this study.

Ecosystem Impacts. A prolonged drought may result in negative environmental impacts. Wells may be affected by flooding and drought. As water levels in wetlands and streams decline and temperatures increase due to a drought, water quality challenges can be exacerbated. Lower water levels can further reduce habitat ranges, increasing predation and encroachment pressures.

Adaptation Options

Wells can reduce its exposure to drought-induced water supply shortages by acquiring additional water supplies. This might involve digging deeper wells for those using well-water or partnering with nearby municipalities. Decreasing municipal, industrial, business, and residential demands through water conservation also reduces sensitivity. Reducing water demand may also keep more water in local waterways, which can help ecosystems survive drought as well.

Marine Habitat Health

Risks

Not only are increased atmospheric temperatures warming ocean waters, but greenhouse gas emissions are also altering ocean currents and the chemistry of the sea (NOAA, 2012). Carbon dioxide is absorbed by ocean water, creating a much more acidic oceanic environment across the globe. The acidity represents a threat to all marine life, but shellfish are particularly vulnerable to ocean acidification (Maine Department of Marine Resources).

Vulnerabilities

In the Gulf of Maine, temperature, nutrient flows, and salinity are affected by the Labrador Current from the north and the Gulf Stream from the south (Jacobson et al, 2009). Climate change is expected to significantly alter these ocean currents, which would impact the composition and distribution of marine species in the Gulf of Maine. Warmer temperatures may benefit lobster but drive cod north. In the short-run, the Gulf of Maine may actually become colder and less saline as Arctic ice melts (NOAA, 2013). While this study does not provide a vulnerability analysis for marine habitats, past reports indicate that nearshore habitat and those species with lower tolerance for temperature variation and pollution will be at a higher risk.

Adaptation Options

It is impossible to isolate marine habitat from oceanic changes. While climate change mitigation options have the potential to reduce changes to ocean circulation and chemistry, some changes may be inevitable in the long term. Wells can invest in increasing the adaptive capacity of its marine habitat by increasing high quality habitat areas and reducing additional pressures on marine ecosystems (e.g. pollution and fishing). Individuals and industries that are reliant on marine ecosystems may want to further investigate projected impacts of climate change on the Wells marine environment and develop adaptation strategies accordingly.

a) Protect Salt Marshes

b) Vegetated Waterway Buffers

Figure 25. Adaptation Options for Marine Habitat Health

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Executive Summary: Sand Replenishment, www.OCtheBeach.com; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Wetland Restoration; Woonasquatucket Wetland Restoration http://www.dem.ri.gov/programs/benviron/water/wetlands/wetplan.htm.; Tree canopy, Courtesy of Douglas Still, City Forester, Providence, RI; Water Conservation, Wikicommons; Protected Salt Marshes, Wells Reserve at Laudholm

Salt marsh Photo credit to Erica Simmons

Street Flooding Photo credit to the Town of Wells

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2010 Storm Damage. Bridge Closed Photo credit to the Wells Reserve at Laudholm

Adaptation Options for Flooding: Restored Wetland. Three Bridges Foundation; Sand Replenishment, www.OCtheBeach.com; Buy-backs, Photo by Marilee Caliendo/FEMA; Flood Resilient Building. Photo by: Jeffrey Tortaro, Design firm: Tsoi/Kobus & Associates in Cambridge, MA; Low Impact Development, Southeast Michigan Council of Governments.

Adaptation Options for Heat Waves: Building Retrofits. RafterTales; Cooling Center. NYC Urbanlife Blogspot; Shade Trees, Courtesy of Douglas Still, City Forester, Providence, RI

Adaptation Options for Marine Habitat Health: Protect Salt Marshes. Photo credit to the Wells Reserve at Laudholm; Vegetated Waterway. Photo credit to Erica Simmons

Appendix 1: Methodology for Downscaled Projections and Sea Level Rise

The Wells downscaled projections were generated as output from four different global circulation models (GCMs) that have been well-established and evaluated in the peer-reviewed scientific literature: 1) the US National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; 2) the United Kingdom Meteorological Office's Hadley Centre Climate Model version 3 (HadCM3); 3) the National Center for Atmospheric Research's Parallel Climate Model (PCM) and 4) Community Climate System Model Version 3 (CCSM3). These models have different climate sensitivities, where sensitivity refers to the amount of temperature change resulting from a doubling of atmospheric CO_2 concentrations relative to pre-industrial times. GFDL, CCSM3, and HadCM3 have medium sensitivity, and PCM has a low sensitivity.

Each global model produces output in the form of geographic grid-based projections of daily, monthly, and annual temperatures, precipitation, and other climate variables. GCMs operate on the scale of hundreds of miles, which is too coarse a resolution to distinguish changes across different towns and cities in a given region, such as New England. However, scientists used state-of-the-art statistical downscaling models to capture historical relationships between large-scale weather features and local climate, and use these to translate future projections down to the scale of local weather station observations. In this project we used a relatively new statistical downscaling model, the Asynchronous Regional Regression Model (Stoner, et al, 2012). This report uses the projections downscaled to the meteorological station in Portland, Maine, because it is the closest station to Wells.

Two different climate change scenarios drove the projections from the GCMs: a high emissions scenario (A1fi) and a low emissions scenario (B1). The high emissions scenario assumes that the world will experience economic growth dependent primarily on fossil fuels and that atmospheric concentrations of CO_2 will reach 940 parts per million by 2100. The low emissions scenario assumes that economies will shift to cleaner, less fossil-fuel intensive technologies, and that atmospheric concentrations of CO_2 will reach 550 parts per million by 2100[4]. The purpose of choosing a high emissions and a low emissions scenario is to create a likely range of future climatic change that Wells may experience during the 21st century.

4 The emissions scenarios and GCM simulations used in this report consist of models that contributed to phase 3 of the Coupled Model Intercomparison Project (CMIP3). These are the results presented in the Intergovernmental Panel on Climate Change (IPCC) Third (2001) and Fourth (2007) Assessment Reports. More recent scenarios combined with CMIP5 climate projections were recently released (September 2013) in the IPCC Fifth Assessment Report.

The projections are also presented in three time frames: short term, medium term, and long term. The short term refers to the time period between 2010 and 2039, the medium term refers to the time period between 2040 and 2069, and the long term refers to the time period between 2070 and 2099. The historical baseline refers to the time period between 1980 and 2009. We averaged the results of the historical baseline and climate projections over their respective 30-year timeframes. This period is long enough to filter out any inter-annual variation or anomalies and short enough to show longer climatic trends.

Table A1: Global Circulation Models

Origin	Model	Scenarios	Equilibrium Climate Sensitivity (°C)*
National Center for Atmospheric Research, USA	CCSM3	A1fi, B1	2.7
National Center for Atmospheric Research, USA	PCM	A1fi, B1	2.1
Geophysical Fluid Dynamics Laboratory, US	GFDL CM2.1	A1fi, B2	3.4
UK Meteorological Office Hadley Centre	HadCM3	A1fi, B3	3.3
* data from IPCC 2007 Fourth Assessment Report, Chapter 8.			

Table A2: Downscaled Projections for Wells: Temperature Anomalies

Temperature Anomaly (°F)							
	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
	1980-2009	Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Annual TMIN	37.0	39.0	39.1	40.0	41.8	40.8	44.7
Annual TMAX	55.6	57.7	57.7	59.0	60.7	59.9	64.1
Winter TMIN	16.5	19.4	19.5	20.5	22.4	21.5	25.9
Winter TMAX	34.2	36.4	36.1	37.2	38.2	38.0	40.7
Summer TMIN	57.1	58.8	59.1	59.9	61.4	60.6	64.0
Summer TMAX	76.5	79.0	79.2	80.9	83.2	81.9	87.3

Table A3: Downscaled Projections for Wells: Temperature Extremes

Temperature Extreme (days per year)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
<32°F	147	136	136	130	117	126	100
>90°F	4	6	8	12	25	15	49

Table A4: Downscaled Projections for Wells: Precipitation

Precipitation (inches)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
Annual mean	46.2	48.1	47.1	48.8	49.4	50.2	51.7
Winter mean	10.2	11.4	11.5	12.0	11.9	12.7	13.9
Summer mean	10.5	9.6	9.6	9.8	10.2	9.0	10.3

Table A5: Downscaled Projections for Wells: Extreme Precipitation Events

Extreme Precipitation (events per year)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
1" in 24 hrs	10.9	12.6	13.1	13.2	13.4	13.5	14.9
2" in 48 hours	4.6	6.8	6.7	7.5	8.0	8.2	9.8

Extreme Precipitation (events per decade)							
	Historical	**Short Term (2010-2039)**		**Medium Term (2040-2069)**		**Long Term (2070-2099)**	
	1980-2009	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
4" in 48 hrs	9.0	9.4	6.2	9.4	11.9	12.0	13.6

Relative sea level rise (SLR) at a site is considered to be the sum of global climate change and local subsidence. Other factors such as circulation changes are not considered. Based upon research done in Portsmouth, NH (Wake et al, 2011), it is only necessary to consider global changes in the area of Portsmouth NH since subsidence is insignificant. Therefore the estimates of global SLR can be taken from Figure A1 (Vermeer and Rahmstorf, 2009), similar to the later projections of Parrish et al (2012) used for the US National Climate Assessment. For any particular time period, we suggest using the upper and lower values in the gray areas in the curve. Thus the SLR is approximately 1 to 2 feet by 2050 and 3 to 6 feet by 2100.

Table A6: Downscaled Projections for Wells: Sea Level Rise

Sea Level Rise (feet)						
	Short Term (2025)		**Medium Term (2050)**		**Long Term (2085)**	
	Low Emissions	**High Emissions**	**Low Emissions**	**High Emissions**	**Low Emissions**	**High Emissions**
Sea Level Rise	0.5	0.8	1.0	1.7	2.0	4.7

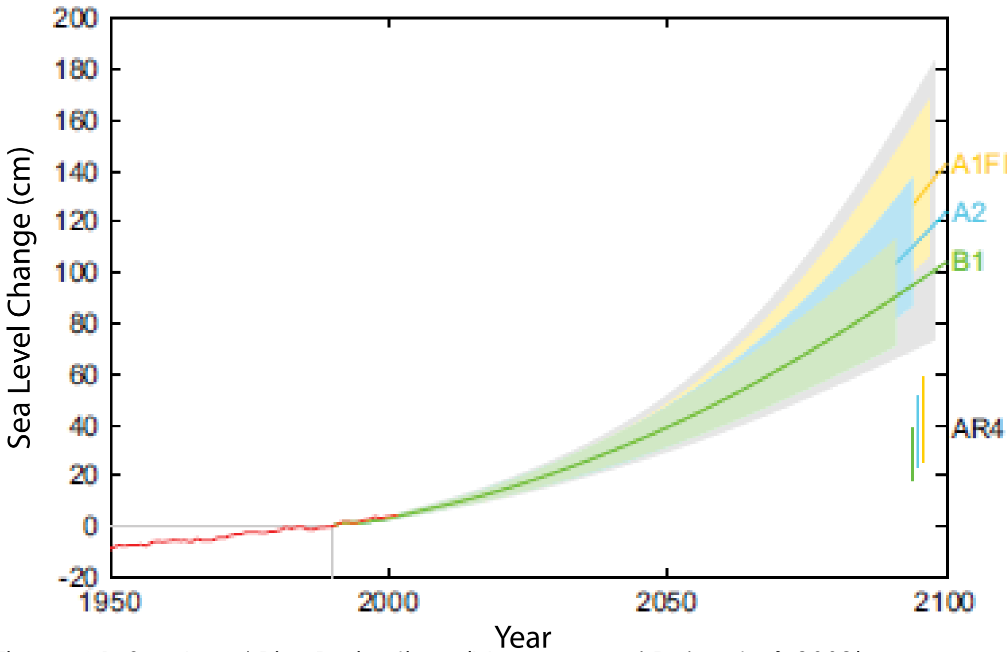

Figure A1. Sea Level Rise Projections *(Vermeer and Rahmstorf, 2009)*

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Parris, Adam, Peter Bromirski, Virginia Burkett, Daniel R. Cayan, Mary Culver, John Hall, Radley Horton, et al. 2012. Global sea level rise scenarios for the US National Climate Assessment. Silver Spring, MD: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Oceanic and Atmospheric Research, Climate Program Office.

Stoner, AMK, K Hayhoe, X Yang and DJ Wuebbles. 2012. An asynchronous regional regression model for statistical downscaling of daily climate variables. Int. J. Climatol. DOI: 10.1002/joc.3603.

Vermeer, Martin, and Stefan Rahmstorf. 2009. "Global sea level linked to global temperature". Proceedings of the National Academy of Sciences of the United States of America. 21 (51): 21527.

Wake, C., Burakowski, E., Kelsey, E., Hayhoe, K., Stoner, A., Watson, C., and Douglas, E., December, 2011. Climate Change in the Piscataqua / Great Bay Region: Past, Present, and Future, University of New Hampshire.

Appendix 2: Additional Resources

Below are additional resources on climate change risks and adaptation at various scales.

Maine

Seagrant. Maine Property Owner's Guide to Managing Flooding, Erosion & Other Coastal Hazards: http://www.seagrant.umaine.edu/coastal-hazards-guide

University of Maine, 2009. Maine's Climate Future: An Initial Assessment. http://climatechange.umaine.edu/research/publications/climate-future

Northeast

Union of Concerned Scientists, 2007. "Confronting Climate Change in the Northeast: Science, Impacts, and Solutions." http://www.northeastclimateimpacts.org/

Wake, Cameron, 2011. "Climate Change in the Piscataqua/Great Bay Region: Past, Present, and Future." CarbonSolutionsNE.org

National

National Research Council, 2010. "America's Climate Choices; Panel on Adapting to the Impacts of Climate Change." National Academies Press, Washington D.C. http://www.nap.edu/catalog.php?record_id=12783

National Climate Assessment Development Advisory Committee. Draft Climate Assessment Report 2014. http://ncadac.globalchange.gov/.

United States Global Change Research Program, 2009. "Global Climate Change Impacts in the United States". Second National Climate Assessment. http://www.globalchange.gov/what-we-do/assessment/previous-assessments/global-climate-change-impacts-in-the-us-2009

International

IPCC. 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds)Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2013. Summary for Policymakers. In: Climate Change. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental vPanel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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