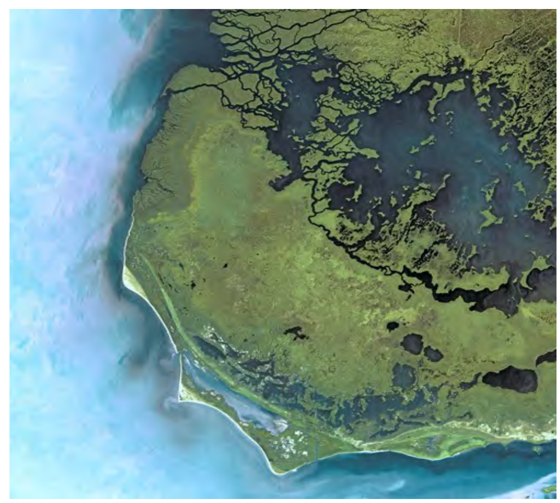
The State of Climate Adaptation in Water Resources Management: Southeastern United States and U.S. Caribbean



2017

Rachel M. Gregg, Whitney Reynier, Alessandra Score, and Laura Hilberg

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Introduction

On May 9, 2013, concentrations of carbon dioxide (CO_2) in the atmosphere first exceeded 400 parts per million (ppm) – a measurement not seen in human history. The burning of fossil fuels is adding carbon to the atmosphere faster than natural processes can remove it, resulting in changes that society must address. Decision makers are faced with the challenge of developing and implementing management options that are suitable under changing climate conditions. Strategies undertaken to address the causes and effects of global climate change are classified as either *mitigation* or *adaptation*. Mitigation strategies help reduce the rate and extent of change by reducing greenhouse gas emissions or enhancing carbon uptake and sequestration. Adaptation strategies help people prepare for, respond to, and recover from the unavoidable effects of climate change.

Climate-induced effects on the water cycle are altering hydrologic systems, causing negative effects on ecosystems and human communities. In turn, these changes will affect how managers and planners approach water resources management. Practitioners are frequently overwhelmed by climate change – what will happen, how will it affect the resources and communities we care about, and what can be done to address these concerns. Despite the wide range of potential changes that may occur in a changing climate, there are a number of options that managers can take to help address these changes in water resources management. Climate adaptation actions are taken to either avoid or take advantage of climate change impacts, either by decreasing vulnerability or increasing resilience. The purpose of EcoAdapt's State of Adaptation Program[1] is to promote adaptation action by (1) providing real-life, practical adaptation case studies to catalyze creative thinking, and (2) synthesizing information collected through interviews and surveys to further develop the field of study and promote adaptation action. We use the information collected to create synthesis reports, such as this one, and share the case studies and other resources through the Climate Adaptation Knowledge Exchange (CAKE; www.CAKEx.org), a website that supports open access information exchange between practitioners. CAKE includes case studies, a library, community forum, directory of individuals and organizations interested and/or engaged in adaptation, and tools section of resources for adaptation action.

The intent of this report is to provide a brief overview of key climate change impacts and a review of the prevalent work occurring on climate change adaptation in the Southeastern United States and U.S. Caribbean, especially focusing on activities as they relate to water resources. The Southeastern United States includes Alabama, Louisiana, Georgia, Mississippi, Tennessee, Kentucky, South Carolina, North Carolina, Virginia, Arkansas, and Florida. Puerto Rico and the U.S. Virgin Islands (USVI) comprise the U.S. Caribbean region. This report presents the results of EcoAdapt's efforts to survey, inventory, and, where possible, assess climate-informed water resources action in the region.

First, climate change impacts and secondary effects on regional water resources is summarized, focusing on changes in air and water temperatures, precipitation patterns, sea levels, and water chemistry (i.e. pH, dissolved oxygen, salinity), followed by a discussion on how the

[1] http://ecoadapt.org/programs/state-of-adaptation

aforementioned issues combine to influence water supply, demand and use, quality, and delivery. The results of a survey sent to federal, tribal, state, and other practitioners to identify challenges, needs, and opportunities for climate-informed water resources management are presented. Summaries of and trends in commonly used adaptation approaches and examples from the survey and other resources are then presented in four broad categories (Gregg et al. 2011, 2012, 2016):

1. **Capacity Building**: Strategies include conducting research and collecting additional information, conducting training and planning exercises, improving public awareness and education, developing tools and resources, and monitoring impacts and effectiveness of adaptation actions.
2. **Policy**: Strategies include developing adaptation plans and policies, creating new or enhancing existing policies, and developing adaptive management strategies.
3. **Natural Resource Management and Conservation**: Strategies include enhancing areas under protection, restoring critical ecosystems, and reducing non-climate stressors.
4. **Infrastructure, Planning, and Development**: Strategies include improving existing or designing new infrastructure to withstand the effects of climate change, incorporating climate change into community and land use planning, creating or modifying development measures (e.g., removing shoreline hardening, encouraging low impact development), and developing disaster preparedness plans and policies.

Eighteen case studies are examined on how various practitioners are integrating climate change into water resources management. The report concludes with a guide to the current suite of tools available to support adaptation action in water resources management, planning, and conservation.

Climate Change in the Southeastern United States and U.S. Caribbean

The Southeastern United States and U.S. Caribbean includes Alabama, Louisiana, Georgia, Mississippi, Tennessee, Kentucky, South Carolina, North Carolina, Virginia, Arkansas, Florida, Puerto Rico, and the USVI. These landscapes include coastal plains, the Piedmont plateau, and the southern Appalachian Mountains, and this diversity gives the region a variable climate influenced strongly by factors such as latitude, topography, and bodies of water. In general, temperatures are hot and humid, but decrease in northern latitudes and higher elevations, and precipitation decreases with distance from the coast (Kunkel et al. 2013). Climate variability in the region is also strongly influenced by the Bermuda High, a high-pressure system typically located off the Atlantic Coast. The Bermuda High pulls moisture to the north and west from the Atlantic and the Gulf of Mexico, creating hot, humid summers and contributing to frequent afternoon and evening thunderstorms. Changes in the position of the Bermuda High strongly influence both temperature and precipitation, as well as severe weather and the track of tropical storms and hurricanes (Kunkel et al. 2013). Other patterns that influence weather in this region are the Atlantic Multidecadal Oscillation (AMO) and the El Niño-Southern Oscillation (ENSO).

The high climatic diversity of the Southeastern United States increases its vulnerability to a variety of extreme weather events, including heavy downpours, floods, and droughts, all of which can influence water resources in this region (Ingram et al. 2013). Over the last 30 years, the Southeast has been affected by more billion-dollar weather-related disasters than any other region (Figure 1), with coastal states experiencing more hurricanes, and inland states experiencing ice storms and tornadoes (NOAA 2017). The high population density and extensive urban development in the Southeast place further stress on natural resources, and this increases the likelihood of damage to infrastructure and disruption of basic services and economic activity during climate disasters.

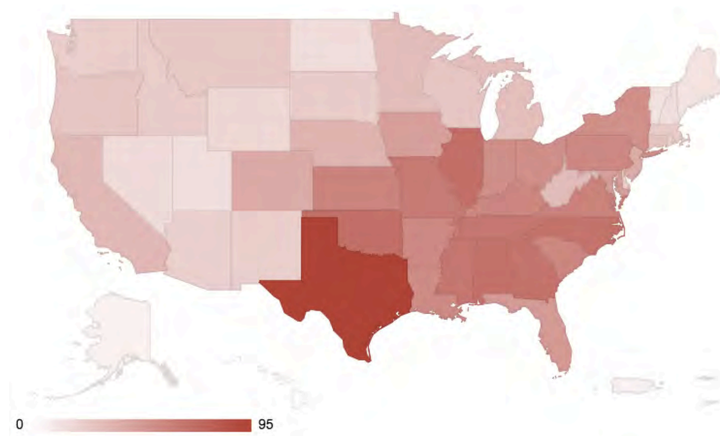

Figure 1. Billion-dollar weather and climate disasters between 1980 and 2017 (as of October 2017).

The region is at greatest risk from sea level rise, extreme heat, hurricanes, and decreased water availability (Carter et al. 2014). Water supplies may be threatened by drought, contamination, and increasing needs associated with agriculture, energy production, and population growth. Water supplies may be further impacted by the destruction of infrastructure and systems in the wake of large natural disasters, tornados, and floods.

Air Temperature

Temperatures in the United States have increased by almost 2°F since the 1880s, and the last decade was the warmest on record (Walsh et al. 2014). In the Southeastern United States, average daily temperatures range from a winter minimum of 20°F in the southern Appalachians and 60°F in southern Florida, to a summer maximum of 95°F in the lower Mississippi Valley and 75°F in northern high-elevation areas. Temperatures vary less from one season to another in the tropical climate of the Caribbean, where the average minimum temperature is 50°F in the high-elevation Cordillera Central Mountains of Puerto Rico (an elevation of over 4,000 ft) and average high temperatures reach 95°F in the drier parts of southwestern Puerto Rico (Kunkel et al. 2013).

Table 1. Observed and projected changes in air temperatures.

General Trend: ↑	
Observed Changes	**Projected Changes**
The Southeastern and Caribbean United States is one of the few regions globally where a steady upward trend in temperature did not occur in the 20th century (Carter et al. 2014). These areas have been referred to as "warming holes", and are not yet understood, though many theories have attempted to explain the phenomenon (such as increased cloud cover and soil moisture limiting temperature increases) (Pan et al. 2004). The Southeast went through a warm period in the 1930s and 1940s, and a cooler period in the 1960s and 1970s (Carter et al. 2014). Since the 1970s, the average annual temperature has increased by 2°F (Carter et al. 2014), and 2001-2010 was the warmest decade on record in that region (Kunkel et al. 2013). The annual number of days over 95°F has increased since 1970. The number of freezing days has declined by 4–7 days per year since the mid-1970s (Karl, Melillo, and Peterson 2009). The annual temperature in Puerto Rico has risen by 1.8°F since 1900 (PRCCC 2013), and other Caribbean islands have showed similar trends. These increases are also correlated with warmer sea-surface temperatures that occur with the AMO and ENSO events (Kunkel et al. 2013).	Air temperature is expected to increase an additional 2–6°F by 2100, though actual warming rates will vary by sub-region. For example, inland zones could experience temperature increases of up to 9°F by 2100, while coastal states will likely see increases of 2.5–4°F by 2100 (Ingram et al. 2013). The majority of warming will likely occur during summer months, with increases of up to 10.5°F possible in that season (Karl, Melillo, and Peterson 2009). Temperature increases in the Caribbean are projected to be smaller, with a possible increase of 4.5°F by 2080 for Puerto Rico and the USVI (other climate models predict ranges between 4.5 and 8.1°F). Higher warming will likely occur over land (Karmalkar et al. 2013). The number of days over 95°F are expected to increase in the region, with South Florida seeing the greatest increase of up to 35 additional over-95°F days per year by mid-century (Ingram et al. 2013). The number of 95°F days in a row is also expected to increase by 97–207% (Kunkel et al. 2013). The Caribbean will see a significant increase in the number of warm nights, with the warmest 10% of nights in the 20th century becoming eight times more likely by the end of the century (Biasutti et al. 2012).

Secondary impacts

- **Frequency, duration, and intensity of heat waves**: Heat waves pose a serious threat to public health, affecting vulnerable populations more heavily (e.g., very young and old people, those with chronic health conditions, low-income families who may not be able to afford fans or air conditioning). Respiratory and cardiovascular diseases are strongly associated with heat waves, and vector- and water-borne diseases also become more of a threat. Heat waves lead to greater water and electricity use, which can stress existing infrastructure and lead to shortages (Kunkel et al. 2013).
- **Increased evapotranspiration:** Warmer air can hold more water vapor, causing higher rates of evaporation and plant transpiration. Elevated evapotranspiration rates resulting from higher temperatures can reduce soil moisture, groundwater recharge rates, total streamflow, and streamflow rates, reducing overall water availability for ecosystems and human use (Ingram et al. 2013).
- **Growing season:** Longer growing seasons have some benefit for crops, but they also increase water demand, possibly reducing available water for all sectors in the Southeast (Ingram et al. 2013).
- **Range shifts:** Warmer temperatures could facilitate shifts in native and agricultural species' ranges, primarily moving northward and upward in elevation. Water availability is a critical determinant of the limits of both aquatic and terrestrial species' ranges (Kirschbaum 2000; Louthan 2016).
- **Phenology shifts:** The timing of seasonal events, such as bird migration, insect emergence, tree budding, and flowering have already begun to respond to warming temperatures by occurring earlier in the year (USA National Phenology Network 2013). A mismatch in these events (e.g., flowering before migratory butterflies have arrived) and the availability of water could have serious implications for natural systems.
- **Soil moisture and drought risk:** Warm temperatures increase the rate of water evaporation and exacerbate water stress on plants, fish and wildlife (Berg et al. 2014).
- **Invasive plants and pests:** Warmer weather can allow invasive insects, such as the wooly hemlock adelgid in the southern Appalachians, to thrive by allowing them to overwinter and accelerating their growth and reproduction (Carter et al. 2014). Similarly, invasive plants can expand their ranges in warm temperatures, invading already-disturbed areas. Invasive-dominated ecosystems have been shown to use more water than native-dominated habitats (Cavaleri and Sack 2010).

Example: Increases in temperature impact the agricultural industry in many ways, including crop damage from heat stress and lowered milk production and birthing rates in livestock. Warmer temperatures also increase the amount of water needed to irrigate crops, because plant transpiration rises and moisture evaporates faster from the soil. Combined with changes in precipitation, increased evapotranspiration rates could significantly impact the region's water resources; currently, 17% of cropland in the Southeast is irrigated (about 88,800 mi^2). The region is responsible for about 15% of the total water used for agriculture in the United States, with Arkansas ranking second in the country for agricultural water use after California (Ingram et al. 2013).

Precipitation

Precipitation varies widely in the Southeast and Caribbean United States, influenced strongly by moisture sources and topographic features (e.g., the Gulf of Mexico and the Appalachian Mountains) (Kunkel et al. 2013). Annual precipitation totals in the Gulf Coast regions of Louisiana, Mississippi, Alabama, and the Florida Panhandle can be over 60" of rain per year, while inland areas such as Virginia, northern Kentucky, central Carolinas and Georgia receive 40–50". The wettest locations are in southwest North Carolina and eastern Puerto Rico, each of which receives over 100" of rain every year (Kunkel et al. 2013). While much of the Southeast and Caribbean region receives little to no snow, the northern areas receive 5–25" per year, and high-elevation sites in the southern Appalachians can receive 100" (Kunkel et al. 2013).

Most precipitation falls during the summer, and least during the winter; interior areas have less seasonal variability. Spring and fall can bring severe weather, including thunderstorms, tornados, and hurricanes; these can contribute heavily to annual rainfall totals. Patterns of precipitation and severe weather are heavily influenced by the Bermuda High, especially in the Caribbean (Kunkel et al. 2013).

Table 2. Observed and projected changes in precipitation patterns.

General Trend: ↑↓	
Observed Changes	**Projected Changes**
Precipitation over the last hundred years has been variable, with large differences observed on annual and decadal scales due to patterns such as the Bermuda High, ENSO, and AMO. Although no significant patterns in annual precipitation totals have been observed, summer rainfall has become more variable in the last 35 years, with extremely dry or extremely wet summers becoming more common (Wang et al. 2010). Historical precipitation data for the Caribbean is limited. However, available data suggests that the area has received 5–30% less rain over the last 30–70 years (Neelin et al. 2006). In the Southeast, very heavy rainfall events have increased by 10–25% over the past 20 years (Kunkel et al. 2013), possibly due to increases in hurricane frequency in the Atlantic basin (Ingram et al. 2013; Landsea et al. 2010).	Through the end of the 21st century, mean annual precipitation is predicted to increase by 2–8% in northern areas of the Southeastern United States, and to decrease by up to 6% in southern areas of the region. Summer precipitation may decrease more relative to other seasons (up to 15%) (Ingram et al. 2013). The number of days with extreme precipitation will likely increase by the mid-21st century, particularly in Kentucky, Tennessee, and along the southern Appalachians (Ingram et al. 2013). Puerto Rico and the USVI are expected to experience larger decreases in precipitation, especially during the wet season when rain could decrease by 18–33% (Karmalkar et al. 2013).

Secondary impacts

- **Hurricanes and tropical storms:** Atlantic hurricanes have become more severe since 1970, though the number of hurricanes has increased only slightly (Ingram et al. 2013; Carter et al. 2014). Over the next century, hurricanes will continue to become more powerful, with higher wind speeds, higher rainfall amounts and rates, and more intense storm surge (Carter et al. 2014; Karl, Melillo, and Peterson 2009). Over the course of one month in 2017, Hurricanes Harvey, Irma, and Maria destroyed several coastal communities in the Gulf Coast and Caribbean, causing between $335-475 billion in damages (Willingham 2017). Hurricane Irma was the strongest ever recorded in the Atlantic and Hurricane Maria was the strongest storm to hit Puerto Rico in a century (Fritz 2017).

- **Flooding:** The frequency of extreme precipitation events has been increasing over past 20 years, especially in the lower Mississippi River Valley and northern Gulf Coast (Kunkel et al. 2013). Downpours are expected to continue to increase, and increased intensity may overwhelm current flood capacity of infrastructure (Berry et al. 2011). Most major rivers in the Southeast are prone to flooding. Floods can cause catastrophic damage, contamination of water supplies, and increased incidence of waterborne disease.
- **Drought:** The percentage of areas experiencing moderate to severe drought has increased by 12% over the past three decades. Summer drought has increased by 14%, and fall drought increased by 9%, despite the fact that precipitation tends to increase across the region in that season (Carter et al. 2014). Frequency, duration, and intensity of droughts will likely continue to increase as temperature rises and precipitation patterns change (Karl, Melillo, and Peterson 2009). Increased demand for freshwater may exacerbate the effects of drought in the region (Kunkel et al. 2013).
- **Soil moisture:** Decreases in precipitation or changes in seasonal precipitation patterns can have large impacts on soil moisture, affecting crops and stressing forests.
- **Freshwater availability:** Net freshwater supply is expected to decline over the next several decades, particularly in western portions of region where supply may decrease up to 6.4%. The Southeastern Atlantic seaboard may see up to a 3.6% increase in water availability (Carter et al. 2014).
- **Wildfire:** Over 25 million acres in the region are at moderate to extreme risk of fire, particularly Florida (Andreu and Hermansen-Báez 2008). The Southeast has high numbers of wildfires per year, partly because of the long growing season (providing ample fuel), and many communities are at risk because of extensive urban development. The region is more likely to have large fires than most other areas in the United States (Andreu and Hermansen-Báez 2008).
- **Landslides:** Landslides are relatively common in Puerto Rico, which experiences one to two large landslides every year (Lepore et al. 2012). They primarily take place during extremely heavy rainfall in the steep central region of the island, and can cause severe property damage, injury, and loss of life (Lepore et al. 2012).

Example: Major flooding events, such as those that occurred during Hurricane Katrina, can disrupt navigation on the Mississippi River, preventing ships from travelling upriver and damaging ports. After Hurricane Katrina, grain transport was halted for several weeks and delays continued for several weeks, causing a drop in national grain exports for 2006 (Wilbanks & Fernandez 2012).

Freshwater Temperature

Increasing air temperatures also drive increases in water temperature, which take place in both inland freshwater sources and in the ocean. Many other factors influence water temperature, however, including stormwater runoff from urban areas, discharge from the cooling processes in power plants, reservoir releases, groundwater inputs, and canopy cover/shade (Marion et al. 2014).

Table 3. Observed and projected changes in freshwater temperatures.

General trend: ↑	
Observed Changes	**Projected Changes**
A recent study (Marion et al. 2014) found that water temperature increased significantly in 62 out of 91 streams in the Southeast between 1960 and 2007. The average temperature increase among the 62 streams was 0.25°F per decade (actual increases ranged from 0.14–0.52°F per decade), with the largest increases occurring in the Appalachian region (Marion et al. 2014). Maximum monthly stream temperature had increased significantly in a greater number of streams (71 out of 91 sites), averaging 0.36°F per decade (Marion et al. 2014).	Marion et al. 2014 estimate that water temperatures will likely rise in 100% of the 91 streams selected for analysis. Stream temperatures are predicted to increase 0.38–0.63°F per decade between 2011 and 2060. Within the Southeastern region, coastal streams are projected to have the smallest increases (Marion et al. 2014). Maximum monthly temperature is expected to increase by 0.45°F at all sites (Marion et al. 2014).

Secondary impacts

- **Increased waterborne pathogens:** Warmer water is more suited to the survival of harmful algae and bacteria. Bacterial infections (such as *Vibrio*) found in water bodies have been reported both one month earlier and one month later than traditionally observed (Carter et al. 2014).
- **Dissolved oxygen**: Water temperatures control dissolved oxygen levels in aquatic systems; high temperatures cause low dissolved oxygen levels, leading to hypoxic conditions (Saari et al. 2017).
- **Algal blooms:** Harmful algal blooms and several disease-causing agents are expected to increase in inland and coastal waters, and also to appear in areas where they were excluded historically (Carter et al. 2014). These can include *Karenia brevis*, the dinoflagellate that causes the deadly "red tide" in Florida, and ciguatoxin, which is consumed by fish. Ciguatera fish poisoning (CFP) affects 50,000 to 500,000 people a year. In the United States, it primarily affects people in the Virgin Islands, Puerto Rico, south Florida, and Hawaii (Ingram et al. 2013).

Example: Increases in the temperature of coldwater streams in the southern Appalachians drastically reduce suitable habitat for coldwater fish such as brook trout (*Salvelinus fontinalis*). Brook trout cannot survive in water temperatures over 45°F, and they also require high levels of dissolved oxygen, which decreases in warm water (Marion et al. 2014). Coldwater fish are under additional stress from habitat loss and human-made barriers that limit movement (e.g., dams and culverts).

Ocean Temperature

Sea surface temperatures (SST) are strongly influenced by air temperature, though ocean currents, wind speed, and cloudiness can also affect temperatures (Griffis and Howard 2013). Because ocean temperatures are so variable, it is difficult to predict them with confidence; however, sea surface temperatures are strong drivers of precipitation amounts and patterns, including drought and severe weather events. This is particularly true in the Caribbean region, where they are the primary influence on seasonal precipitation (Karmalkar et al. 2013).

Table 4. Observed and projected changes in ocean temperatures.

General trend: ↑	
Observed Changes	**Projected Changes**
The ocean has absorbed approximately 84% of the added atmospheric heat between 1955 and 2008, increasing the temperature of the top 2,300 ft of water by a global average of 0.36°F (Griffis and Howard 2013).	SSTs in the North Atlantic are expected to continue rising in the 21st century, with the greatest increases of up to 5.4°F occurring in the sub-tropics around South Florida and the Bahamas (Biasutti et al. 2012).
Multiple studies have concluded that SSTs off of the East Coast in the North Atlantic have increased by 2.88°F in the 20th century; and 0.58–1.2°F in the tropical North Atlantic (Santer et al. 2006).	SSTs in the Caribbean region may increase by 1.8–6.3°F by 2080 in a high-emissions scenario (Karmalkar et al. 2013).

Secondary impacts

- **Sea level rise:** Warm temperatures change the density of ocean water, leading to thermal expansion. This is one of the drivers of sea level rise, and was responsible for up to 30% of the observed rise between 1961–2003 (Cazenave and Llovel 2010).
- **Range shifts:** Aquatic organisms such as phytoplankton, fish, and marine mammals may move into cooler waters as ocean temperature continues to rise.
- **Dissolved oxygen:** Warmer temperatures cause increased metabolic rates in aquatic organisms, leading to higher consumption of oxygen and resulting declines in dissolved oxygen levels (Najjar et al. 2010; Doney et al. 2012).
- **Coral bleaching:** High temperatures are one of a number of factors that can contribute to coral bleaching events, as well as salinity, acidity, turbidity, and pollutant levels.

Example: Puerto Rico is surrounded by up to 1,930 mi^2 of coral reefs, which provide shoreline protection and drive a significant part of the tourism industry in the area (PRCCC 2013). However, corals are very sensitive to sudden changes in water temperatures. Increases of as little as 1.8°F over a period of several weeks can cause the expulsion of the zooxanthellae from within the corals. As a result, the corals lose their color and turn bright white (Buddemeier, Kleypas, and Aronson 2004). Coral bleaching events such as these leave corals vulnerable to injury or death. The first reports of widespread coral bleaching events occurred in the 1980s (Buddemeier, Kleypas, and Aronson 2004), and coral cover has decreased by about 80% in that time (Gardner et al. 2003).

Sea Level

In the Southeast, over 4,970 miles of coastline are vulnerable to sea level rise (Marion et al. 2014). Rates of sea level rise are influenced by terrestrial ice melt, the thermal expansion of warming water, land subsidence (i.e. land sinking because of erosion, groundwater depletion, or natural gas extraction), and short-term climate variation (e.g., ENSO).

Table 5. Observed and projected changes in sea levels.

General trend: ↑	
Observed Changes	**Projected Changes**
Global sea levels have been rising over the course of the 20th century, with rates accelerating sharply since the 1930s (Cazenave and Llovel 2010). Over the last 50 years, global sea levels have risen an average of 0.06" per year (Cazenave and Llovel 2010). Total sea level rise over the 20th century averaged approximately 8" (Carter et al. 2014), and sea levels are currently rising at a rate of 0.13" per year (Cazenave and Llovel 2010). Some areas may be experiencing faster rates of sea level rise due to land subsidence (Mitchum 2011). For example, Louisiana is experiencing relative sea level rise of 0.37" per year (Ingram et al. 2013), and many coastal wetlands have been inundated, including over 1,880 mi^2 of Louisiana wetlands since 1930 (Carter et al. 2014).	Sea level in the Southeast and Caribbean regions is expected to closely match global rates (Carter et al. 2014), which are projected to rise by between 0.65–8.2 ft by the end of the century (Parris et al. 2012; Sweet et al. 2017). Coastal areas most vulnerable to sea level rise include Louisiana, Mississippi, southeastern Florida, southeastern South Carolina, North Carolina, and Virginia. Major cities at risk include New Orleans, Miami, Tampa, Charleston, Virginia Beach, and San Juan (Puerto Rico) (Carter et al. 2014).

Secondary impacts

- **Storm surge:** Increasing storm intensity, coupled with sea level rise, makes storm surge a larger threat to low-lying urban areas, transportation corridors, and coastal ecosystems.
- **Erosion:** Wave action can erode coastlines, causing additional loss of land. The effect is pronounced in areas of Puerto Rico; for instance, the coastline around Rincón is currently eroding at a rate of 3.3 ft per year (Carter et al. 2014).
- **Saltwater intrusion:** Saltwater intrusion into freshwater aquifers and drainage basins can contaminate industrial, municipal, and agricultural water supplies, as well as compromise freshwater fisheries and natural systems by altering salinity levels. Saltwater intrusion reduces available groundwater for coastal agriculture, and during drought periods, coastal rivers can experience increased surface water salinity for miles inland (Ingram et al. 2013).

Example: Terrebonne Parish in Louisiana has lost 340 mi^2 of coastal land since 1956, at a rate of up to 10 mi^2 per year. In 2009, the parish created a Comprehensive Plan for Coastal Restoration, which provided 170 strategies and possible projects that the parish could implement to preserve and restore coastal ecosystems, as well as recommendations and possible funding sources (Halcrow 2009; Feifel 2010).

Dissolved Oxygen

Climate change could cause significant degradation of the Southeast's abundant water resources by altering water chemistry. One of the factors contributing to decreased water quality is low dissolved oxygen, which occurs because of a combination of factors including high temperatures, low flows, and pollutants. Areas of very low dissolved oxygen are termed hypoxic zones in which very little aquatic life can survive (CENR 2010).

Table 6. Observed and projected changes in dissolved oxygen.

General trend: ↓

Observed Changes	Projected Changes
The number of coastal water bodies with reports of hypoxia increased over the course of the 20th century, peaking in the 1980s and 1990s; reports of hypoxia have decreased gradually since then. The Gulf of Mexico and the South Atlantic regions have the largest percentage of water bodies with hypoxic zones in the United States (51% and 55% in the 2000s, respectively, down from a high of 84% and 91% in the 1980s and 1990s) (CENR 2010). The second-largest hypoxic zone in the world encompasses 7,788 mi^2 of the Gulf of Mexico at the mouth of the Mississippi River (Griffis and Howard 2013).	Dissolved oxygen is expected to continue to decline in both saltwater and freshwater sources, due to increasing temperatures and decreasing water levels. Globally, dissolved oxygen in oceans could decrease by 2–4% by 2100 (Cocco et al. 2013). An increase in river discharge over the next century is expected to increase the size of the Gulf of Mexico hypoxic zone, though a 45% reduction in nitrates and phosphorus loading could shrink the size of the zone by up to 80% (Greene, Lehrter, and Hagy 2009).

Secondary impacts

- **Calcification:** Oxygen levels affect calcification of aquatic organisms such as shellfish and coral. One study found that hypoxic conditions decreased the rate of coral reef calcification in darkness by 51–75% (daytime calcification responded more strongly to pH levels) (Wijgerde et al. 2014).
- **Shifts in marine organism distribution:** Large numbers of aquatic organisms are killed within hypoxic zones, including fish and immobile organisms. Some species can detect areas with low oxygen and respond by migrating away (in the case of plankton, migrating vertically within the water column to stay closer to the surface) (Wannamaker and Rice 2000); these shifts can have cascading effects on marine food webs.

Example: Federal and state agencies and tribes have been working to reduce the size of the Gulf of Mexico hypoxic zone to less than 1,900 mi^2, primarily by reducing nitrogen and phosphorus loading in the Mississippi River watershed (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008). However, in August 2015 the National Oceanic and Atmospheric Administration (NOAA) announced that the hypoxic zone in 2015 is 6,474 mi^2 – three times the size of the goal set in 2008. Heavy rains throughout the watershed and high levels of nutrient runoff likely contributed to the increase over the size in 2014 (5,052 mi^2) (NOAA 2015).

pH

The ocean absorbs excess atmospheric carbon dioxide (CO_2), which results in a chemical reaction with water that creates carbonic acid, leading to decreased pH (more acidic water) (Griffis and Howard 2013). Like oceans, freshwater systems can become more acidic via terrestrial runoff and atmospheric deposition of pollutants such as sulfur dioxides and nitrogen oxides (e.g., acid rain) (Driscoll et al. 2001). Atmospheric pollutants can travel great distances from their original source, resulting in acidified waters far from the source location.

Table 7. Observed and projected changes in pH.

General trend: ↓	
Observed Changes	**Projected Changes**
Scientists estimate that oceans have already absorbed 25% of the CO_2 released over the past 200 years, and that ocean pH has fallen from a logarithmic value of 8.2 to 8.1 (an increase in acidity of 30%) (Feely, Doney, and Cooley 2009).	An additional decrease of 0.3 pH units to 7.8 could occur by the year 2100 (Feely, Doney, and Cooley 2009). Because CO_2 is more easily absorbed in cold water, the Southeastern United States and Caribbean regions may be less affected than regions at higher latitudes.

Secondary impacts

- **Reduced calcification:** When CO_2 is absorbed by water, a chemical reaction is triggered in which hydrogen ions bind with free carbonate ions, reducing the carbonate available to organisms for the creation of calcite (e.g., skeletons and shells) (Feely, Doney, and Cooley). Shifts in available carbonate could significantly impact the health of mussels, oysters, coral, and other species that rely on internal or external calcified structures.
- **Shifts in species distribution and range:** Acidification can cause reduced body size, slowed growth, and mortality in aquatic organisms, which in turn can affect the distribution and range of species within oceans and freshwater systems (Mora et al. 2013).

Example: Acidic deposition is the process by which air pollutants such as sulfur dioxide, nitrous oxide, and particulates are transferred to aquatic and terrestrial ecosystems (Driscoll et al. 2001). This issue first came to light in the late 1960s and early 1970s, and was addressed in part by the Clean Air Act of 1970, which put limits on emissions of sulfur dioxide and nitrous oxide. Emissions remain high in several Southeastern states, including Tennessee, North Carolina, Louisiana, and Florida (Driscoll et al. 2001). Acidic deposition can affect freshwater rivers and streams as runoff collects acidifying agents and runs into larger watersheds. However, larger rivers are somewhat buffered from these effects, and evidence suggests that many, including the Mississippi River, are gradually becoming more alkaline because of a variety of factors, including more limited emissions and the use of agricultural lime (Stets, Kelly and Crawford 2014).

Salinity

Ocean salinity decreases with the addition of freshwater sources, which can include rivers, precipitation runoff, and ice meltwater (Cazenave and Llovel 2010); it is also influenced by precipitation and evaporation over the ocean (Boyer et al. 2007). Increasing salinity is highly correlated with increasing ocean heat content, though this relationship is slightly weaker in the western North Atlantic, Gulf of Mexico, and Caribbean Sea (Boyer et al. 2007).

Table 8. Observed and projected changes in salinity.

General trend: ↑	
Observed Changes	**Projected Changes**
Overall, the salinity of the western North Atlantic has increased slightly since 1967, though it has held relatively steady in the Gulf of Mexico and Caribbean Sea. Water in the sub-polar North Atlantic has decreased in salinity, probably due to the addition of meltwater from polar ice (Boyer et al. 2007). In the last 20 years, freshwater has decreased at depths of up to 1,300 ft, and freshwater has increased below 4,265 ft in the North Atlantic (Boyer et al. 2007).	Salinity may decline in the future, because of large freshwater inputs from the melting Greenland Ice Sheet (Burkett and Davidson 2012). However, ocean salinity levels are fairly localized, and other factors could affect smaller-scale changes. For instance, drought could greatly reduce freshwater flow from rivers into the ocean, increasing salinity (Gregg et al. 2012).

Secondary impacts

- **Water column stratification:** Increased levels of freshwater input could affect the mixing of deep and shallow water (freshwater is less dense, so it would not sink at the same rate). This would slow the turnover of nutrients from the ocean floor, affecting phytoplankton and thus, the entire marine food web (Griffis and Howard 2013).
- **Changing ocean currents:** Freshwater inputs (such as those from the polar ice caps) could also affect ocean current patterns, as freshwater sinks more slowly. Scientists do not currently know how much meltwater would need to be added in order to change thermohaline circulation (Griffis and Howard 2013).
- **Saltwater intrusion:** This process can affect the availability of freshwater as multiple additional climate stressors (e.g., sea level rise, low streamflow, etc.) interact to increase the salinity of groundwater along coastal areas.

Example: Many urban areas in the Southeastern United States rely on large coastal rivers for their water supply. A combination of rising sea levels, low streamflows, and practices such as groundwater pumping changes the point where saltwater and freshwater meet, allowing saltwater to infiltrate farther upstream and penetrate groundwater supplies (Berry et al. 2011; Conrads et al. 2013). Many cities in Florida are already experiencing salinization in drinking water supplies, including the City of Hallandale Beach, which has already been forced to abandon six of their eight drinking water wells (Berry et al. 2011).

Summary

Despite being generally considered an area with abundant water resources, climate stressors (e.g., temperature, precipitation, drought, hurricanes, and sea level rise), are likely to affect water resources in the Southeastern United States and U.S. Caribbean (Table 9). The effects of climate change also interact with non-climate stressors, which include increasing populations, development pressure, pollution, and invasive species.

Table 9. Trends in climatic factors expected to affect the region.

Climate Factor	General Trend	Observed Changes	Projected Changes	Compounding Factors[2]
Air temperature	↑	Increased by 2°F since 1970	Increases, with warming most severe in summer	• Natural climatic events, such as ENSO and AMO
Precipitation	↑↓	5–30% less rain over the last 30–70 years, 10–25% more heavy rainfall events, more variable summer precipitation	Increases in northern areas and decreases in southern areas, with decreases in summer precipitation across the region	• Natural climatic events, especially the Bermuda High (also ENSO and AMO) • Frequency and strength of tropical storms, which can provide a large percentage of annual rainfall locally
Freshwater temperature	↑	Increased in 62 of 91 streams by average of 0.25°F per decade since 1960	Increases of 0.38–0.63°F per decade in 100% of southern Appalachian streams	• Influenced primarily by air temperature • Shade from riparian vegetation decreases water temperature
Ocean/Sea surface temperature	↑	Increased by 0.58–2.88°F in the 20th century	Largest increases in the Southeast may be up to 5.4°F off of South Florida; increases of 1.8–6.3°F by 2080 in the Caribbean.	• Natural climatic events, such as ENSO and AMO • Changes in land use and land cover
Sea level	↑	Global sea levels have risen by 0.65 ft in the 20th century, at 0.06" per year	Predicted to rise between 0.65–8.2 ft by 2100	• Land subsidence (i.e. sinking of land mass) • Natural climatic events, such as ENSO and AMO • Storm surge and erosion can exacerbate effects as coastline recedes

[2] Compounding factors are variables that complicate the effects of climate change in either a positive or negative way. Examples include short-term climatic variation events (e.g., ENSO), land use, pollution, or sedimentation.

Climate Factor	General Trend	Observed Changes	Projected Changes	Compounding Factors[2]
Dissolved oxygen	↓	Number of water bodies with reports of hypoxia increased over the last 100 years, but decreased since the 1990s	Continued declines in freshwater and saltwater (2–4% by 2100 in oceans); further increase in size of Gulf hypoxic zone	• Upwelling waters from the ocean floor play a role in mixing oxygen • Increased temperatures decrease the ability of oxygen to dissolve into water • Nutrient loading leads to eutrophication (e.g., algae blooms and other organisms that rapidly consume oxygen)
pH	↓	pH has fallen from 8.2 to 8.1 over the last 200 years (30% increase in acidity)	Additional decrease to pH of 7.8 could occur by 2100	• Upwelling of water from the ocean floor • Nutrient loading • Amount of runoff from land (including urban) • Air pollutants such as sulfur dioxide and nitrous oxide (can travel great distances, so local effects are highly variable)
Salinity	↑	Has held steady or increased slightly since 1967; shallow water has become more saline and deep water fresher in the last 20 years	May decrease due to large inputs of freshwater from melting ice; increase in saltwater intrusion into freshwater sources	• Rate of melting ice (e.g., Greenland Ice Sheet) • Drought could decrease freshwater flow and increase salinity locally • Sea level rise, low stream flows, and groundwater extraction and low stream flows can increase saltwater intrusion • Sea level rise can inundate freshwater wetlands

Water shortages can occur as a result of changes in both supply and demand. Although climate change has the potential to significantly disrupt both, the direct effects will decrease water supply most heavily. Decreased precipitation or changes in precipitation patterns (e.g., more rain in the winter and less in the summer) could drastically decrease the amount of water available for urban and agricultural use. Drought may become more common, and, additionally, rising temperatures could contribute to drought conditions by increasing evapotranspiration. In the Caribbean region, drought is one of the most frequent climate hazards, causing economic loss in the agriculture and tourist industries, high food prices, water restrictions, and decreases in public health, among other consequences (Farrell, Trotman, and Cox 2010). Saltwater intrusion into coastal aquifers, drainage basins, and freshwater rivers can also decrease water supplies, contaminating freshwater supplies (Ingram et al. 2013). In addition to impacts on human communities, water shortages also affect plant and animal health and survival, and can place significant stress on ecosystem functioning.

Water supplies are affected by not only the amount of water, but also water quality. Rising water temperatures; changes in salinity, pH, and dissolved oxygen levels; and non-climate stressors such as pollution can all decrease water quality. Extreme events can contaminate stored water supplies and/or water sources, especially during large flood events. Changes in water quality affect aquatic organisms greatly, both in marine and freshwater environments. With the decline of vulnerable organisms such as coral, economic losses can occur related to the tourism and fishing industries, among others.

Over the next century, the demand for freshwater will probably continue to increase, even as supplies of freshwater become less dependable. Rising temperatures can accelerate water loss through evaporation and plant transpiration, increasing water demands to maintain functioning ecosystems. Additional water will be required for crop irrigation, as well as for cooling in populated areas. Periods of drought could greatly exacerbate these conditions and lead to widespread shortages in freshwater supplies, particularly in the western part of the Southeast (Sun et al. 2013).

Populations in the Southeastern United States are continuing to increase, especially in coastal areas where population density and development is very high. This growth greatly increases pressure on freshwater supplies (Carter et al. 2014). In many places, coastal areas lie below sea level, placing those urban communities at especially great risk from sea level rise, storm surge and damage to infrastructure. The spatial distribution of populations intersect with social, political, and cultural issues as well, placing some sectors of the population at much higher risk from climate change effects (Levy et al. 2010). This is particularly true when the discussion centers around safety and the fulfillment of basic needs, such as access to fresh, clean water. Extreme events such as hurricanes can make these distinctions clear, as communities in poverty are more likely to have failing infrastructure, inadequate transportation, and fewer resources to draw upon for recovery from a disaster (Levy et al. 2010).

Existing infrastructure is already burdened in many places from rising sea levels, hurricanes and other severe weather events, and increasing demand. Extreme events are the greatest threat to infrastructure (Wilbanks and Fernandez 2012), and severe storms such as Hurricanes Andrew and Katrina can devastate communities with long-standing consequences. Water storage is a component of infrastructure that is largely lacking in the Southeast and Caribbean regions, and will be vital to maintaining freshwater supplies in future climate conditions (Carter et al. 2014).

Climate-Informed Water Resources Management: Challenges, Needs, and Opportunities

Management Challenges

Challenges associated with water resources management, planning, and conservation revolve around four interacting components – supply, demand and use, quality, and delivery (Figure 2).

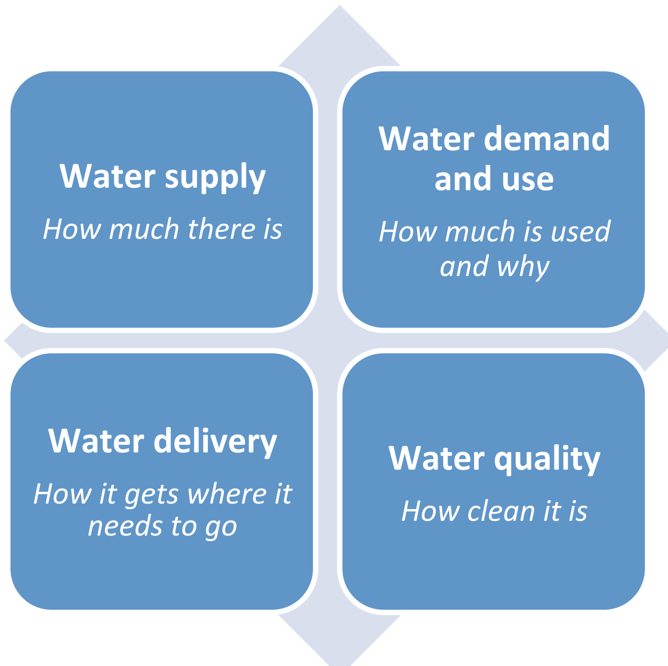

Figure 2. Four interlinked components of water resources management.

Climate change will pose significant challenges to water resources, affecting when, where, and how much clean water is available for various uses. Climate-driven changes will create highly variable conditions that will complicate the business-as-usual (or stationarity-driven [Milly et al. 2008]) approach commonly employed by water management entities. The **supply** of water is influenced by climate-driven changes in the magnitude, frequency, and duration of water flows. **Water demand and use** are tightly linked to water supply. As temperatures rise and population growth increases, the demand for water will likewise increase. Water shortages and increased competition for water will heighten these issues in the Southeastern United States and U.S. Caribbean. The **quality** of water is also important. Clean, fresh water is a vital resource for ecosystems and human communities. Increasing water temperatures and changes in water chemistry (i.e. salinity, pH, dissolved oxygen) can degrade water quality. Increased nutrient and pollutant runoff can contaminate water sources, particularly during high-flow events. **Water delivery** refers to how water moves through both ecosystems and infrastructure. Water resources infrastructure serves to convey, store, and protect water. Conveyance (e.g., channels, pipes), storage (e.g., reservoirs), and protective (e.g., levees, dams) measures all serve to manage water at specified levels. Existing water resources infrastructure in the region is at risk from severe weather events and will be increasingly threatened by rising sea levels and storms.

Needs Assessment Survey Methods and Results

In order to better understand the needs of water resources professionals (e.g., managers, planners, engineers, etc.) to respond to a changing climate, we released an online survey and collected responses between January 2015 and June 2016. The survey was designed to:

- Assess professionals' understanding and concerns about climate change impacts on regional water resources,
- Document regional activities to prepare for and respond to present and future water resource challenges, and
- Compile needs, opportunities, and barriers in planning for overarching threats to water resources, including changing climate conditions.

Responses were collected through SurveyMonkey, a web-based survey company. The survey was sent to a list of 1,050 individuals, including water resource managers and planners from federal, tribal, state, and local agencies; utilities; and nongovernmental organizations; participants were also invited to share the survey with other interested parties. Through these efforts, we collected 259 complete responses, yielding a 25% response rate.

This section provides a snapshot of the needs expressed by federal, tribal, state, and other practitioners to undertake climate-informed water resources management and conservation.

Survey Respondents

Respondents were asked to identify their position type, professional affiliation, the sector(s) and region(s) in which they work, and the type of water resources and related issues on which they work. Respondents primarily self-identify as resource managers (36%) and scientists (27%) (Table 10). The largest number of survey participants overall represent nongovernmental organizations (29%) (Figure 3). Government agencies include state (18%), federal (13%), municipal/city (8%), county (3%), and tribal (1%) representatives.

Table 10. Survey participants' position types (note: participants selected all relevant job types) (n=259).

Type of Position	Percentage (n=259)
Manager	36%
Scientist/Researcher	27%
Other (e.g., Project Manager, Executive Director, etc.)	15%
Environmental Consultant	11%
Planner	9%
Engineer	7%
Communications/Education	5%
Policy Analyst	4%
Lawyer/Legal Advisor	3%

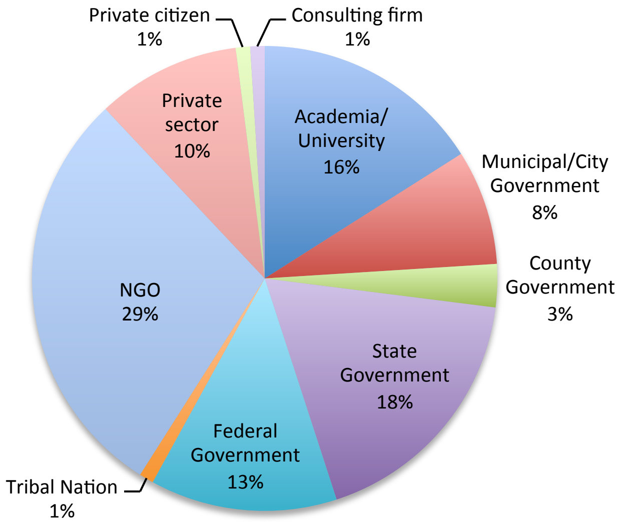

Figure 3. Professional affiliations of survey respondents (n=259).

Respondents were also asked to indicate the geographic area(s) in which they work (Figure 4). Most respondents represent North Carolina (19%), Georgia (15%), Puerto Rico (15%), South Carolina (13%), and Florida (12%).

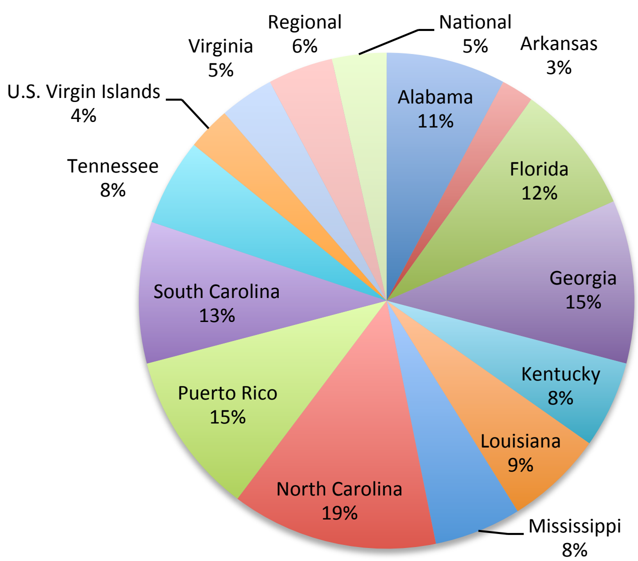

Figure 4. Geographic areas in which respondents work (n=259).

Respondents primarily represent one or more of the following sectors: water resources (52%), conservation/restoration (48%), and education/outreach (41%). Twenty-six percent of respondents represent water utilities and land use planning, followed by research (25%), policy (22%), wildlife (20%), fisheries (19%), forestry (18%), and agriculture (15%), among others (Figure 5).

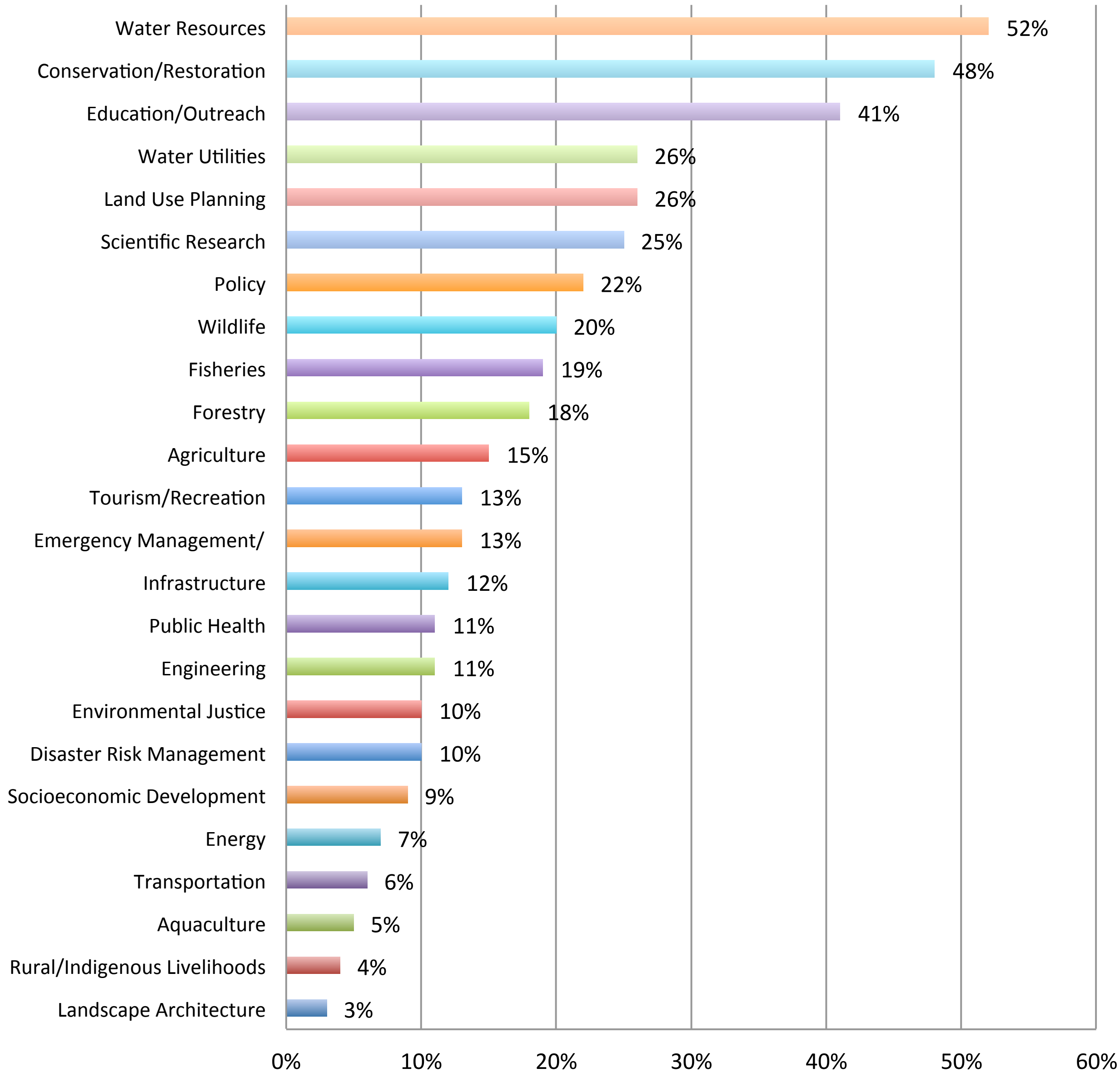

Figure 5. Sectors represented by respondents (n=259).

Overall, survey respondents work on one or more types of water resources issues, including water quality (83%), water delivery (59%), water demand and use (45%), and water supply and storage (42%). Respondents indicated that they manage, interact with, and are concerned about a variety of types of water resources, primarily rivers and streams (71%), watersheds (67%), and wetlands (59%) (Figure 6).

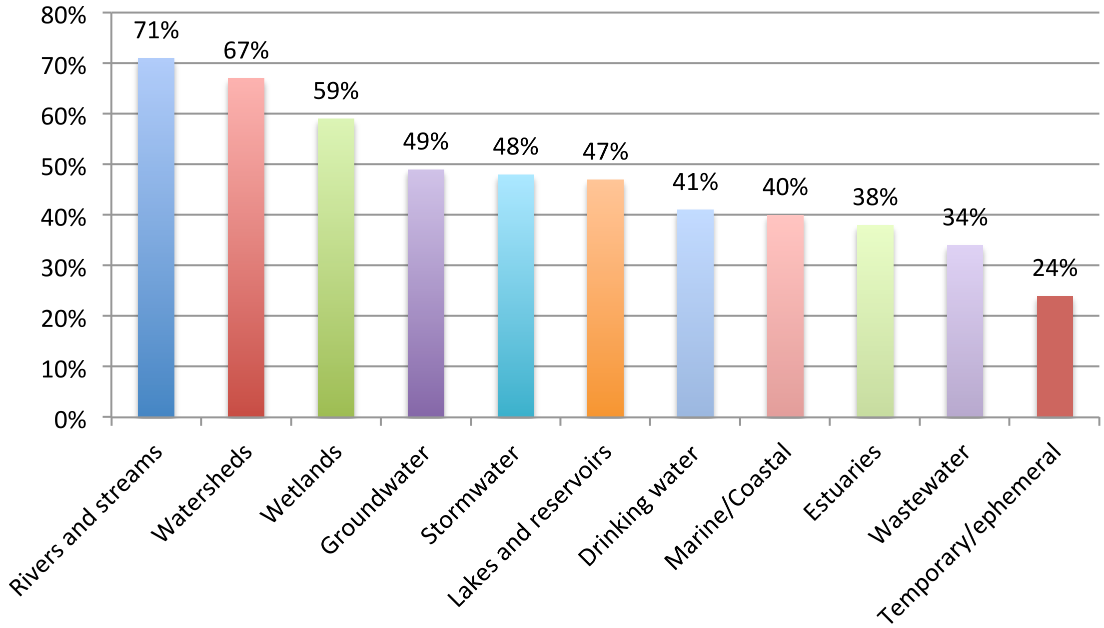

Figure 6. Type of water resources respondents manage and/or are concerned about (n=259).

Respondents were asked if they believe that climate change has had, is having, or is likely to have a significant effect on water resources in the Southeast United States and U.S. Caribbean; eighty-five percent agreed, four percent disagreed, and 11% responded "maybe" (Figure 7). Overall, respondents indicated that they are well (51%) or moderately (45%) informed about climate change; only four percent responded that they were not well-informed (Figure 8).

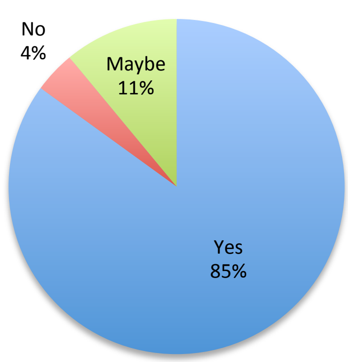

Figure 7. Percentage of respondents who believe climate change is affecting water resources (n=235).

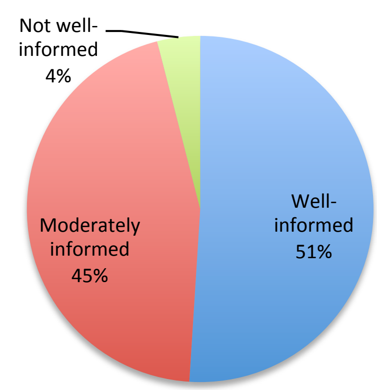

Figure 8. Climate change knowledge level as identified by respondents (n=235).

Threats to Water Resources

Participants were asked to identify existing threats of concern to water resources and rank their level of concern (Figure 9). Climate change is a threat that 88% of respondents are "very" or "somewhat" concerned. Less than five percent of respondents indicate that threats such as drought, flooding, and storms and extreme events are of no concern. Scientists and managers are the most concerned about climate change (57% each) compared to other survey participants. Managers also rank habitat loss or destruction (63%), pollution (55%), flooding (46%), and drought (45%) as their biggest concerns. Among participants that represent water utilities, the issues of broadest concern include pollution (62%), outdated or degraded water infrastructure (56%), drought (52%), and climate change (51%).

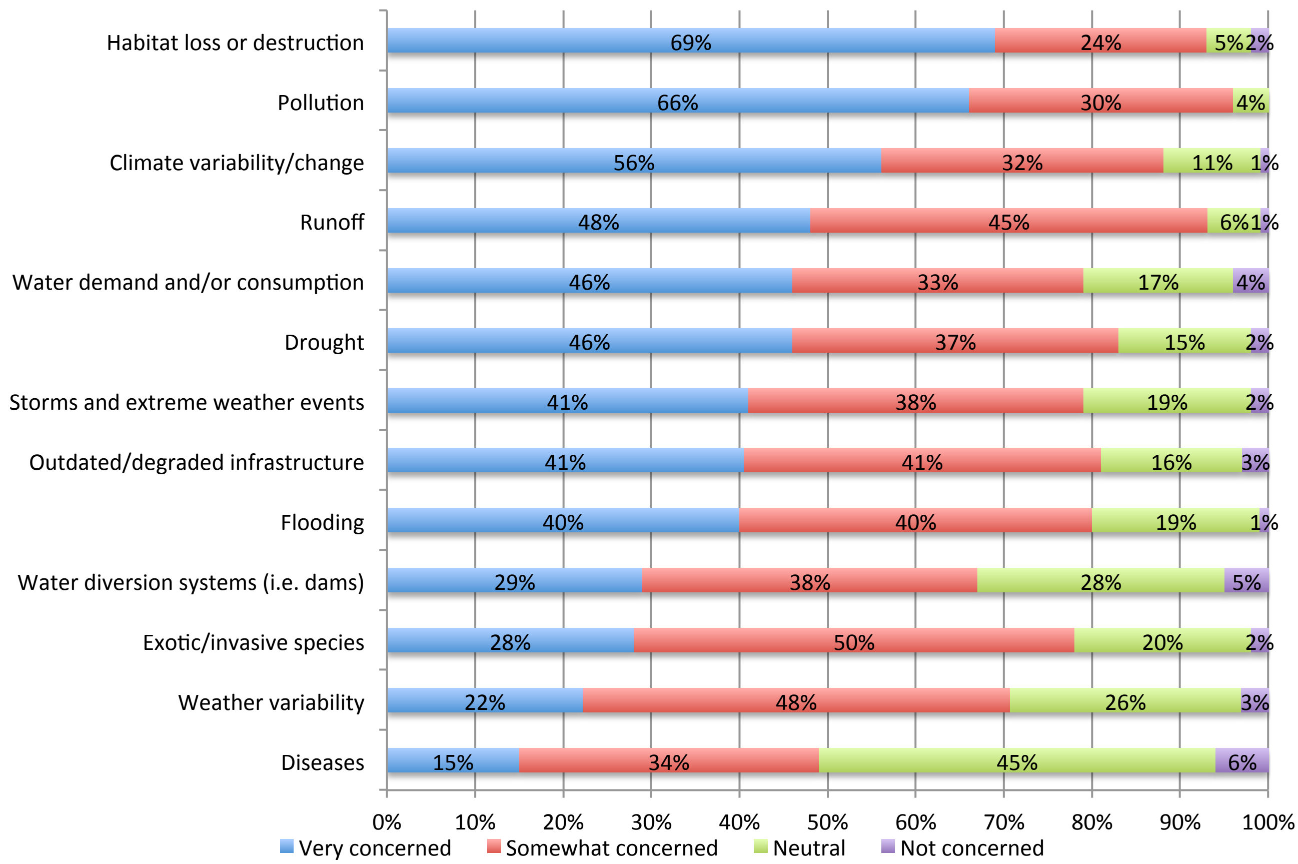

Figure 9. Existing threats of concern to water resources and level of concern of respondents (n=235).

Participants were asked to identify climate-related changes of concern to water resources and rank their level of concern (Figure 10). Changes in water quality are the most frequently expressed concern for 62% of respondents, followed by habitat loss or destruction (53%) and effects on water supply and stormwater runoff (44% each). Less than five percent of respondents indicate that impacts on floodplains, groundwater recharge, and hydrology are of no concern. Managers are very concerned about impacts on water quality (65%), water supply (46%), and habitat (41%), while scientists are most concerned about impacts on habitat (65%), water quality (49%), groundwater recharge (49%), and hydrology (48%). Among participants that represent water utilities, the issues of broadest concern are water quality (67%), water supply (48%), public health (45%), and stormwater runoff (44%). Respondents that represent disaster and emergency management entities rank flooding (71%), storms and extreme events (58%), public health (55%), and public safety (53%) as their top issues.

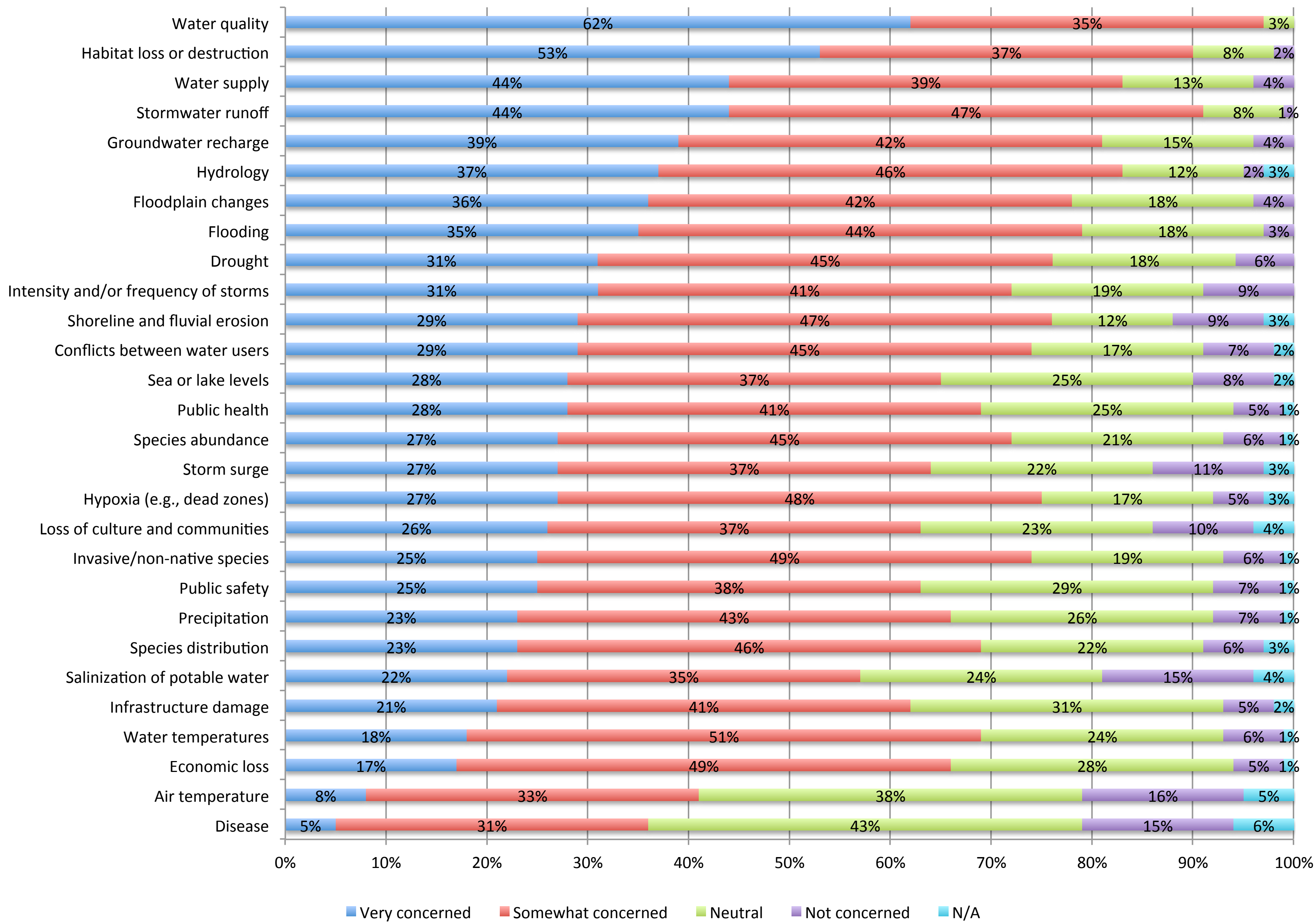

Figure 10. Changes of concern for water resources and level of concern of respondents (n=234).

Adaptation Barriers and Opportunities

Participants were also asked to identify specific barriers and opportunities (i.e. strategies or actions) with respect to managing water resources in a changing climate. The top three barriers to climate-informed water resources efforts noted by respondents who are both engaged in climate adaptation and those who are not include lack of funding, insufficient staff resources and capacity, and current and more pressing issues (Figure 11). Among managers, lack of funding ranked as the highest challenge whether they are engaged in adaptation (59%) or not (36%). Of practitioners representing conservation entities working on climate change, lack of funding (58%) and insufficient capacity (54%) rank highly.

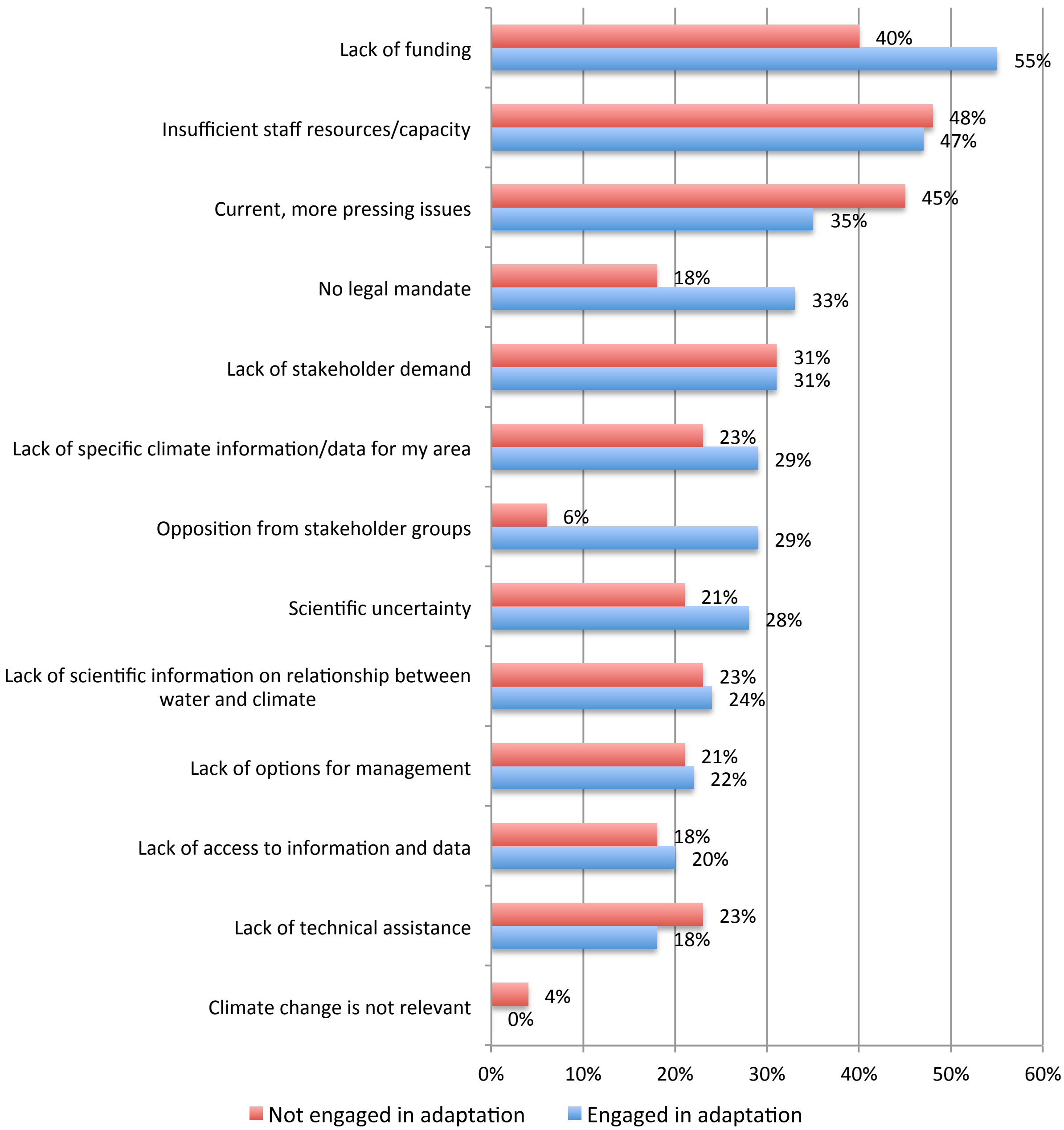

Figure 11. Key barriers noted by respondents who are currently engaged in climate adaptation (n=165; blue) and those who are not (n=62; red).

Participants were asked to prioritize adaptation strategies and actions by specific water resources issues – supply and storage, demand and use, quality, and delivery (Table 11).

Table 11. Respondents' priorities for adaptation options by water resources issue (n=224).

Issue	Adaptation Strategy/Action	Percentage
Supply and Storage	Protect freshwater ecosystems (e.g., enhance buffer zones for streams/rivers that feed aquifers)	82%
	Enhance natural retention of flood water (e.g., floodplain restoration)	69%
	Create drought mitigation plan (e.g., drought monitoring, early warning systems)	62%
	Diversify water supply sources	52%
	Improve forecasting and information	43%
	Increase water supplies and/or storage capacity	38%
	Consider future conditions in water pricing and water trading (e.g., buying/selling water rights)	31%
	Create new reservoirs and retention ponds	22%
	Increase capacity for/utilize desalinization processes to produce fresh water for human consumption and use	21%
Demand and Use	Increase water conservation and efficiency efforts (e.g., educate water users regarding water shortages and quality issues associated with climate change)	75%
	Increase water reuse and recycling (e.g., irrigation, urban/industrial)	75%
	Promote use of alternative water sources for non-potable uses (e.g., rain barrels)	68%
	Reduce water demand (e.g., irrigation, urban/industrial)	59%
	Use modeling to understand extreme precipitation events, sea level rise, storm surges, groundwater conditions, runoff, future water supply etc.	58%
	Prepare for multiple needs of potable and non-potable water sources (e.g., reuse irrigation in agriculture)	56%
Quality	Monitor water quality, surface water conditions, vegetation changes in watersheds	83%
	Increase water quality monitoring	76%
	Assess integrity of water resources infrastructure	49%
	Increase capacity for treatment of degraded water (e.g., injection wells for wastewater treatment and/or aquifer recharge)	37%
Delivery	Implement watershed management (e.g., restore vegetated land cover, manage runoff, mimic natural features and hydrology)	77%
	Limit development within vulnerable watersheds	73%
	Implement green infrastructure (e.g., rain gardens, low impact development methods, pervious pavement, green roofs, swales, etc.)	71%
	Minimize runoff with climate-smart landscaping (e.g., xeriscaping)	63%
	Incorporate climate change into Integrated Water Resources Management	62%
	Improve flood protection measures (e.g., "soft" and "hard" measures)	48%
	Protect resources and infrastructure from flood damage, sea level rise, and storm surge	45%
	Create new/Retrofit water resources infrastructure for storage and delivery	38%
	Enhance flow patterns	30%

Of the more general strategies associated with climate adaptation (Figure 12), respondents indicated that increasing and improving public awareness and outreach efforts related to climate impacts on regional water resources is of highest priority (81%), followed by conducting more research (75%).

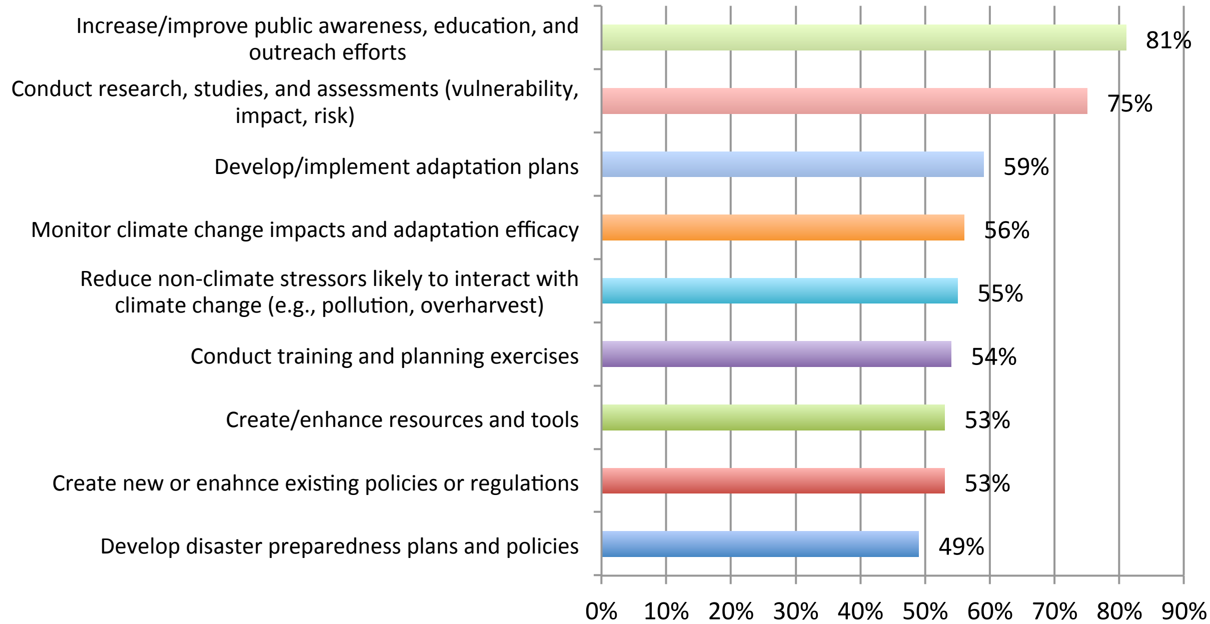

Figure 12. General adaptation strategies prioritized by respondents (n=234).

Knowledge, Products, and Services

Participants were also asked what information they currently use. Respondents indicate that they rely on best practices and lessons learned (82%) to inform their decision-making at work, followed by peer-reviewed scientific literature (69%), case studies (67%), agency plans and policies (54%), traditional knowledge (52%), and spatial data (52%) (Figure 13). Best practices and lessons learned rank the highest for managers (92%), as well as those representing water utilities (90%) and disaster risk management entities (100%). Scientists rank peer-reviewed scientific literature highly (82%), followed by ecosystem/species models (70%) and case studies (65%). Models are used most often by disaster risk management agencies, while hydrological forecasting is used fairly equally across water utilities (48%), engineering companies (46%), and emergency preparedness entities (42%).

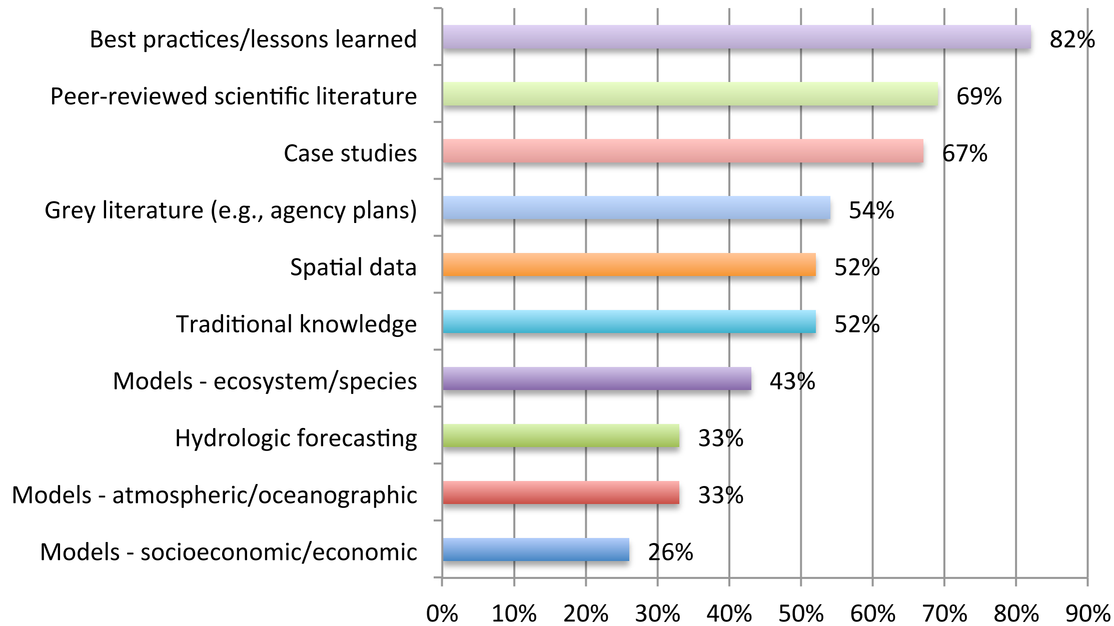

Figure 13. Information currently used to make decisions by survey respondents (n=211).

Survey participants were also asked to identify specific resources and tools they use to make decisions (Table 12). In addition, respondents indicate that resources such as aerial photos, beach erosion and accretion rates, population growth projections, national and state soil surveys, regional water/sewer utility planning studies, U.S. Army Corps of Engineers' (USACE) feasibility studies, and water data from the U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS) are used.

Table 12. Resources and tools used by survey respondents (n=135).

Tool/Resource	Developer/Website
305(b) and 303(d) water quality reports	EPA, state environmental agencies
StormCaster	Atkins, Texas A&M University; http://www.atkinsstormcaster.com
Climate Outlook Maps	National Weather Service Climate Prediction Center; http://www.cpc.ncep.noaa.gov/products/forecasts
Critical Lands and Waters Identification Project	http://fnai.org/clip.cfm
ENSO Forecasts	International Research Institute for Climate and Society; http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current
Climate Reanalyzer	University of Maine Climate Change Institute; http://cci-reanalyzer.org
Flood Map Service Center	Federal Emergency Management Agency; https://msc.fema.gov/portal

Tool/Resource	Developer/Website
Georgia Coastal Hazards Portal	Skidaway Institute of Oceanography, University of West Georgia; http://gchp.skio.usg.edu
National Climate Assessment	U.S. Global Change Research Program; http://nca2014.globalchange.gov
National Centers for Environmental Information	NOAA; http://www.ncdc.noaa.gov
U.S. Drought Monitor	National Drought Mitigation Center, U.S. Department of Agriculture (USDA), and NOAA; http://droughtmonitor.unl.edu
CanVis	NOAA Office for Coastal Management, USDA National Agroforestry Center; https://coast.noaa.gov/digitalcoast/tools/canvis
Sea Level Rise and Coastal Flooding Viewer	NOAA Office for Coastal Management; https://coast.noaa.gov/digitalcoast/tools/slr.html
Conservation Practice Standards & Specifications	USDA Natural Resources Conservation Service; https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps
Web Soil Survey	USDA Natural Resources Conservation Service, National Cooperative Soil Survey; http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
South Atlantic Conservation Blueprint	South Atlantic Landscape Conservation Cooperative; http://blueprint.southatlanticlcc.org/v2.1/index.html
Sea Level Scenario Sketch Planning Tool	University of Florida GeoPlan Center; http://sls.geoplan.ufl.edu

Survey participants were also asked to identify what resources they need in order to effectively engage in climate-informed water resources management, planning, and conservation (Figure 14). Resources of the broadest need include best practices and lessons learned (97%), specific information about the effects of climate change on water resources (96%), case studies (95%), and scientific reports and articles (94%). Decision support tools rank highly among respondents representing wildlife (50%) and conservation (49%). Guidance on communicating climate change to the public and key stakeholders ranks highly among those representing disaster risk management (58%), policy (56%), scientific research (55%), and conservation and restoration (54%). Climate-informed maps are of high interest across the board by communications experts (83%), planners (72%), and scientists (69%). Specific information about climate-induced effects on regional water resources ranks highest among planners (83%), policy analysts (82%), managers (63%), and engineers (56%).

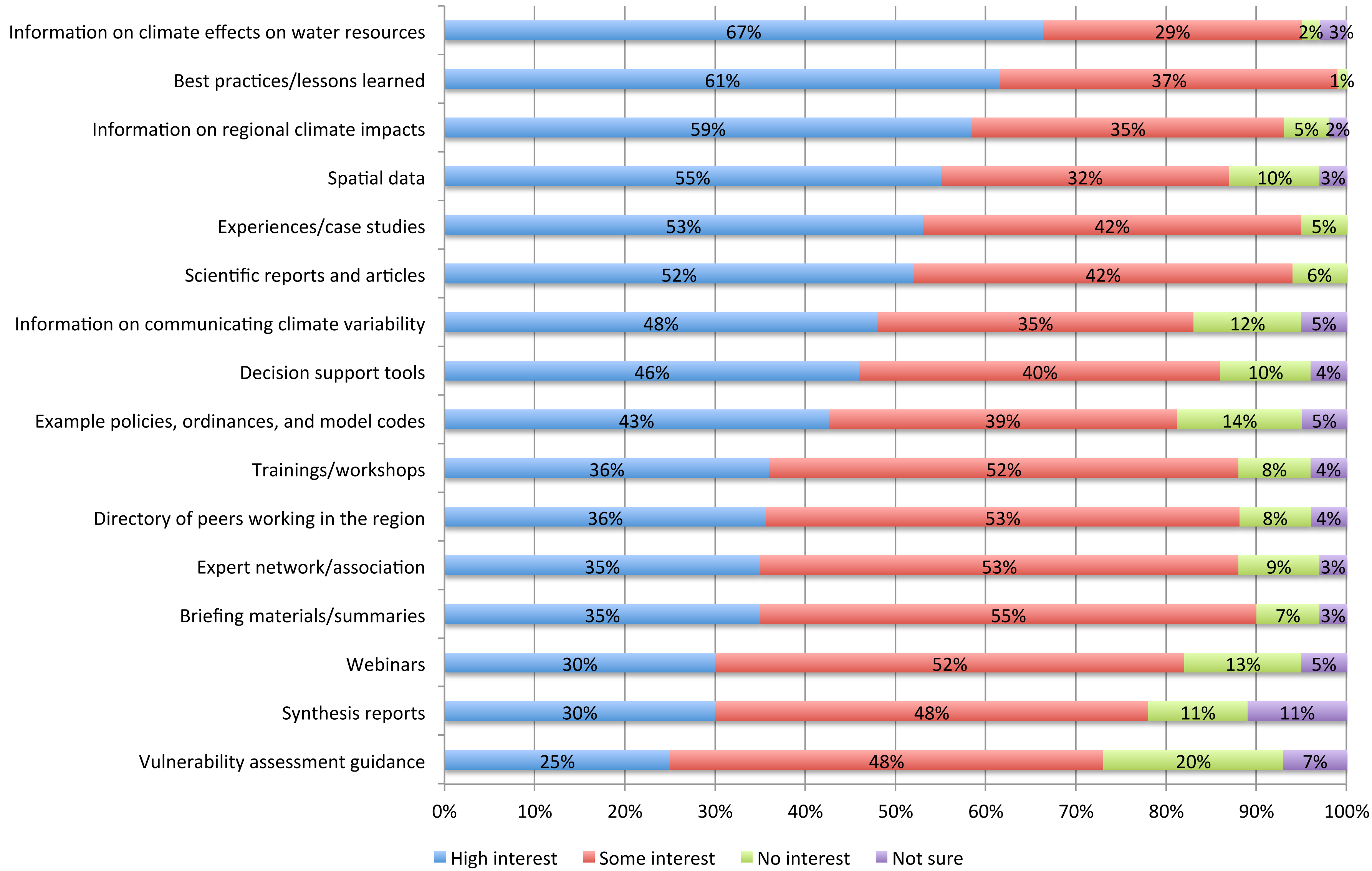

Figure 14. Resource needs ranked by survey respondents (n=209).

Adaptation in practice

Climate change requires the development and implementation of robust management strategies that can help practitioners prepare for, respond to, and recover from impacts. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as an “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2013). Adaptation actions are taken to either avoid or take advantage of climate change impacts, by decreasing vulnerability or increasing resilience. Climate adaptation approaches include supporting resistance, resilience, or response of human and natural systems in the face of change. *Resistance* approaches include actions that reduce the amount of change or increase the ability of systems to withstand change, while *resilience* approaches aim to improve the ability of systems to recover from change (Gregg et al. 2011). *Response* or *transition* actions focus on helping systems accommodate changes that do occur (Millar et al. 2007). Additional approaches include *increasing knowledge* in order to gather more information on climate change and/or management effectiveness, and *enhancing collaboration* to coordinate efforts and capacity across jurisdictions and other boundaries.

Adaptation activities may be grouped in a number of ways. In order to organize our findings for this survey, we grouped adaptation strategies as they relate to water resources management by the following categories – *Capacity Building*, *Policy*, *Natural Resource Management and Conservation*, and *Infrastructure, Planning, and Development* (Gregg et al. 2011, 2012, 2016):

1. **Capacity Building**: Strategies include conducting research and collecting additional information, conducting training and planning exercises, improving public awareness and education, developing tools and resources, and monitoring impacts and effectiveness of adaptation actions.
2. **Policy**: Strategies include developing adaptation plans and policies, creating new or enhancing existing policies, and developing adaptive management strategies.
3. **Natural Resource Management and Conservation**: Strategies include enhancing areas under protection, restoring critical ecosystems, and reducing non-climate stressors.
4. **Infrastructure, Planning, and Development**: Strategies include improving existing or designing new infrastructure to withstand the effects of climate change, incorporating climate change into community and land use planning, creating or modifying development measures (e.g., removing shoreline hardening, encouraging low impact development), and developing disaster preparedness plans and policies.

This section presents examples and notable trends of adaptation projects and initiatives throughout the Southeastern United States and U.S. Caribbean uncovered in this survey; eighteen projects are presented as full case studies.

Capacity Building

Building the capacity of organizations, practitioners, and the public can increase the ability to plan, develop, and implement adaptation actions. Example strategies within this category include designing or reforming institutions to support adaptation, conducting research and assessments, investing in training and outreach efforts, and developing new tools and resources.

Design or reform institutions

An important facet of capacity building as an adaptation strategy is ensuring that institutional support is sufficient and appropriate to address the widespread effects of global climate change at multiple scales. This strategy includes either creating new institutions or enhancing existing institutions by increasing organizational capacity and coordinating planning and management. Examples from our survey include the Jordan Lake Regional Water Supply Partnership, Hampton Roads Special Committee on Recurrent Flooding and Sea Level Rise, and Virginia Coastal Coalition.

In 2009, 13 water providers and municipalities in the Research Triangle Region of North Carolina joined together to collaboratively plan for and implement sustainable and secure regional water management in the face of population growth and increasing climate variability. The established Jordan Lake Regional Water Supply Partnership[3] has since undertaken a variety of planning and implementation projects to increase water supply resilience. The Partnership first developed and published a two-volume, 50-year regional water supply plan which includes: (1) a regional needs assessment that assesses historic and future water demands and current and future water supply sources, systems, and needs at both regional and partner-level scales, and (2) a regional water supply alternatives analysis that explores and prioritizes different opportunities to collaboratively meet the region's water needs through 2060. The plan discusses how climate variability may affect water supply within the region, and several strategies prioritized for implementation help increase the resilience of water supplies (e.g., enhancing regional system interconnectedness, increasing water conservation). At this point, individual partners are implementing projects outlined in the regional plan and applying for state allocations of Jordan Lake water. The Partnership is also collectively mapping how water can be transferred (volume and direction) amongst the entire regional system. The partners hold semi-monthly meetings to discuss progress, updates, and challenges. Moving forward, the Partnership hopes to engage more regional collaborators, explore how and where the Partnership needs to engage with water quality management, develop triggers and protocols to guide interconnection water transfers, and to revise its plan to reflect progress, new needs, and newly available science, including climate information.

The Hampton Roads Planning District Commission in coastal Virginia is compiling and analyzing climate change and management data to better understand how changing precipitation patterns (e.g., flashier storms, larger downpours, and drought episodes) could impact drinking water, water quality, and wastewater and stormwater management. For example, the

[3] Jordan Lake Partnership: http://www.jordanlakepartnership.org

Commission is studying the response of reservoir levels to changing precipitation patterns. Local studies have found that flashier storms and heavier downpours undermine water storage capacity, as water must be released during these precipitation events to avoid reservoir overtopping. In addition, the Commission is studying how shifting precipitation patterns and higher water tables can impact the operations and integrity of wastewater and stormwater infrastructure. For example, higher water tables and larger stormwater volumes as a result of climate change could overload the capacity of current sewer systems, causing overflows that could impair water quality. By summarizing available data surrounding climate change and water resources management and acting as an advisor to both local and state governments, the Commission hopes to create statewide adaptive water resources management policy and legislation and promote projects that will reduce regional vulnerability to climate change impacts on water resources. To further this goal, the Commission established a Special Committee in March 2014 to help the region plan for recurrent flooding and sea level rise; this group will be responsible for developing specific policies and recommendations for local governments, as well as advocating for state support and acting as a liaison between local, state, academic, and federal agencies.

The Virginia Coastal Coalition was founded in 2012 in order to better include the business community in the development of climate change adaptation plans and policy surrounding water-related issues. Past exclusion of business groups from planning processes has led to significant conflicts, including stalled adaptation projects, undermined business interests, compromised communities, and the involvement of state management in largely local issues. The Coalition hopes to improve dialogue between business leaders, community representatives, scientists, and government in order to collaboratively develop adaptation goals and plans that are amenable to all.

Conduct research, studies, and assessments

Collecting information on and understanding climate change are critical steps in taking adaptation action. Identifying how extreme precipitation events, storm surges, and sea level rise affect surface and groundwater conditions and supplies is key to understanding what changes are occurring and the implications of those changes. These activities include climate impacts assessments, vulnerability assessments, and targeted water resources modeling and assessment studies.

Impacts assessments

Impacts assessments provide critical information on specific climate changes of concern and consequences for water resources that may be used to inform management. Examples from our survey include assessments of impacts on 20 basins across the United States and watersheds in the Sunbelt, and from the South Carolina Department of Natural Resources.

With funding from the EPA Office of Research and Development and in collaboration with other contractors, Tetra Tech completed a national-scale modeling study to evaluate how climate change and land use change may impact river basin hydrology and water quality (nutrient and sediment loading). The goals of the study were to identify which watershed and climate data and models could best be used to inform watershed management, and to describe and analyze potential watershed impacts under a variety of future scenarios through the mid-21st century. Twenty large basins across the United States were selected for analysis, including four basins in the Southeast: the Apalachicola-Chattahoochee-Flint Basin, the Georgia-Florida Coastal Plain Basin, the Acadian-Pontchartrain Drainage, and the Albemarle-Pamlico Drainage Basin. A five basin pilot study compared two different watershed models (the Soil Water Assessment Tool [SWAT] and the Hydrologic Simulation Program-Fortran) in combination with various climate land use scenarios to find the best methodological approach for the full analysis. The pilot study found that the SWAT model provided superior results and applicability for watershed planning needs in the context of climate change. Streamflow and water quality impacts were then analyzed for the remaining 15 basins using the SWAT model, six different climate scenarios, and two land use scenarios under the IPCC A2 future emissions scenario. Climate scenarios were derived from global climate model data outputs with statistical and dynamical downscaling, and land use change models compared low versus high urbanization scenarios. Results for the Southeast indicate that the future may contain variable annual flow volumes, shifts in the timing and intensity of flows as a result of increases in winter precipitation and decreases in summer precipitation, and (generally) increases in 100-year peak flow volumes, and sediment and nutrient loads. Models and outputs used in this study are available to the various states, and Tetra Tech has used the methodology developed in this study to work with states on an individual basis. Regional watershed planners can use the modeling results to better understand what types of uncertainty they may face, and to identify management actions that are feasible under a variety of futures.

Researchers based at North Carolina State University and other institutions are working together to better understand interconnections and uncertainties in water supply and demand, management, climate change, population growth, and ecology. Researchers are comparing interactions in four different pilot basins in the Sunbelt, including watersheds in Arizona, Texas, North Carolina, and Alabama. These basins face very different water challenges; comparing their different supply/demand shifts and management responses will help identify water sustainability practices that can be applied region-wide to enhance resilience. To evaluate hydro-climate and hydro-ecological interactions, as well as societal and management responses and influences in these basins, collaborators are utilizing downscaled climate models and hindcasts at 10-30 year intervals, which have more relevance for typical management time planning horizons. These hindcasts and models are being compared to a variety of publically available datasets (i.e. streamflow data, county-level water use, groundwater withdrawals, and ecological trends) to both validate model accuracy and to better understand how different drivers affect water supply and demand. This information will also be evaluated in comparison to different management strategies employed by the various water management agencies to help identify strategies that were successful in sustaining water supply in the past and that can likely be used to enhance the sustainability of water management in a future with population growth and variable climate. This approach also has the potential to be applied in international sustainable water supply planning, and to be applied to assess water quality questions.

The South Carolina Department of Natural Resources conducted an assessment of climate change on the state's wildlife, fisheries, water supply, and other natural resources and provided recommendations on potential response strategies (SCDNR 2013). The assessment identifies that both groundwater and surface water supplies will decline under climate change as demand for water increases. Key strategies recommended to address sea level rise, water quantity, and water quality include modeling marsh migration zones to inform the prioritization and protection of land; maintaining and/or relocating water control structures; developing a basin-wide water supply and demand plan that plans for future needs; and developing a groundwater monitoring network to detect saltwater intrusion. The report was finalized in 2011 but was not publically released until February 2013 due to political pressure.

Vulnerability assessments

Vulnerability assessments and studies help managers evaluate what resources are at risk and why by examining exposure, sensitivity, and adaptive capacity. Assessments are underway or completed for different sectors and communities in the region. Examples from our survey include assessments for Virginia's wildlife, agriculture and forestry in the U.S. Caribbean, and the communities of Rincón, Plymouth, and Dauphin Island.

Wildlife

The Virginia Department of Game and Inland Fisheries recently underwent a revision of the state Wildlife Action Plan. Climate change updates to the plan facilitated the creation of dynamically downscaled climate models that analyzed over 20 climate variables, different time scales, and two different greenhouse gas emission scenarios at 10 km grid scale resolution. These models were used to assess the vulnerability of 20 different aquatic and terrestrial species to projected climate-driven changes. These assessments highlighted the need for proactive management to achieve healthy populations and healthy habitats, which increase resilience and management opportunities for the landscape in the long term. The "healthy habitats and populations" concept was incorporated into the 2015 plan revision, along with more specific climate change priorities such as identifying and creating priority resilient habitat sites, identifying climate change threats, and developing possible adaptation actions.

Agriculture and forestry

The USDA Caribbean Climate Sub Hub for Tropical Forestry and Agriculture conducted a climate change vulnerability assessment of agriculture and forestry practices in the U.S. Caribbean, including Puerto Rico and the USVI (Gould et al. 2015). Increasing temperatures, decreasing rainfall, and more intense storms are likely to lead to both increased incidences of drought and flooding. Key vulnerabilities from climate factors include threats to food security, inundation and salinization of agricultural lands, and increased pest outbreaks. Tourism largely supplanted agriculture as a core economic sector on the islands in the 1960s. Both Puerto Rico and the USVI rely on imported food and domestic products from the continental United States as the local agriculture and forestry sectors are predominantly small-scale. Water is identified as the most valuable and vulnerable resource in the region, and water quantity and quality are some of the highest concerns for decision makers. Storms and intense rainfall events cause increased sedimentation, which in turn affect surface water supplies. For example, high sedimentation rates have led to a sharp decline in storage capacity in Puerto Rico's reservoir system over the last 50 years, which has affected the island's capacity to cope with drought events. Saltwater intrusion into freshwater aquifers used as sources for irrigation water is an increasing concern in the region as well. The assessment includes several potential strategies, including using cover crops to improve soil water holding capacity and infiltration, increasing the efficiency of irrigation and drainage systems, and improving potable water supply use.

Communities

Tetra Tech partnered with NOAA and the Puerto Rico Department of Natural and Environmental Resources, to conduct a vulnerability assessment and adaptation planning project for the municipality of Rincón, Puerto Rico (Tetra Tech 2015). Tetra Tech had initially helped Rincon develop a hazard mitigation plan for submission for Federal Emergency Management Agency (FEMA) funding, and used the models developed for that process to provide a more holistic view of Rincón's vulnerability and risk in relation to climate change. Components analyzed included sea level rise, storm surge, coastal and riverine flooding, and drought across several different time horizons. As a beachfront municipality with the majority of its jurisdiction in a floodplain, Rincón will likely face substantial risk, particularly to its drinking water and wastewater systems.

Several communities in the region have used the Vulnerability and Consequence Adaptation Planning Scenario (VCAPS)[4] tool to support vulnerability assessments. VCAPS, created by North and South Carolina Sea Grant, the University of South Carolina, and the Social and Environmental Research Institute, is a participatory modeling tool that integrates generalized scientific climate data with local knowledge and experience (social drivers), allowing municipal leaders to explore their communities' vulnerability to climate and climate-driven changes by linking climate change trends with local impacts and consequences. VCAPS also highlights where adaptation opportunities exist, facilitating the transition from planning to action. Examples include Plymouth, North Carolina, and Dauphin Island, Alabama.

The Town of Plymouth engaged with North Carolina Sea Grant staff to better understand and address vulnerability to changing environmental conditions (Putnam et al. 2012). Through community interviews, Plymouth residents identified increased flooding as a key concern for their community; they then identified flood-prone areas and outlined key needs for responding to flood risk. The Renaissance Computing Institute developed a flood inundation map based on various river-flooding scenarios. Community members then used VCAPS to assess wastewater infrastructure and stormwater management issues, and vulnerabilities related to increased flooding. This collaborative analysis helped community leaders better understand flooding drivers, discuss the potential flooding impacts on stormwater and wastewater infrastructure and management, and began a dialogue on potential actions to increase community resilience. No definitive actions have come of the process due to lack of funding, but should future funding arise, community members have a good baseline understanding of community flood risks.

[4] Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS): http://www.vcapsforplanning.org/index.html

The Town of Dauphin Island, located on a low-lying barrier island in the Gulf of Mexico, worked with the Mississippi-Alabama Sea Grant Consortium on a multi-year climate resiliency study (Janasie and Deal 2015) to expand upon the town's 2007 Strategic Plan, 2009 Hazard Mitigation Plan, and 2012 draft Comprehensive Plan, and make the island more storm and climate resilient. Started in 2013, this study included a local analysis of climate change projections – including sea level rise, increasing storm intensity and frequency, increasing temperatures, and shifting precipitation patterns (heavier downpours, more drought) – as well as potential impacts on Dauphin Island's ecosystems, residents, and tourism industry (Janasie 2013). In addition, the town participated in a VCAPS workshop to develop policy responses to improve resilience to sea level rise and coastal storms (Tuler and Webler 2013), such as starting a rain barrel program to capture water during downpours; capturing this water reduces flood risk, and the stored water can then be used during drought periods, which will reduce water withdrawals from sensitive and important ecosystems on the island (Janasie 2014). Other potential policy responses included changing local zoning ordinances to minimize flood risk and encourage more resilient structures.

Targeted water resources research

Targeted research programs and studies aid adaptation efforts by establishing a baseline from which to measure change or by addressing the specific uncertainties and variables that may be hindering progress (Gregg et al. 2012, 2016). Examples from our survey include water budgeting for Louisiana, assessments of forests in the Southeast and headwater wetlands of Alabama, a study on how ENSO data can improve point-source discharge permitting, and research on sedimentation rates in the Mississippi River.

Water budgeting

With funding from the Louisiana Department of Natural Resources and the Louisiana Coastal Protection and Restoration Authority, the Water Institute of the Gulf[5] is working with regional partners to develop a water budget and water resources assessment framework to enhance the sustainable management of Louisiana's groundwater and surface water. Louisiana is considered a water-rich state, but it still faces water management challenges, particularly in the face of climate change and population growth. In addition, although there is abundant information currently available and being generated in relation to the abundant waters of the state, compiling and interpreting that information can be a challenge. To facilitate sustainable planning and management of Louisiana's water by decision makers, the Water Institute of the Gulf is developing a framework for analyzing water resources, which will incorporate a variety of metrics, including water quantity and quality, location, input/output and groundwater/surface water movement and relationships, current and potential uses and withdrawals, and allocations for various sectors (including industry, agriculture, residential, and natural resources). The Institute will then conduct two or three case studies, applying the framework to various hydrologic areas within Louisiana to exhibit how it can be used to investigate various water scenarios, identify areas of concern, and develop management options across the state. This framework will allow water managers and decision-makers to

[5] Water Institute of the Gulf: http://thewaterinstitute.org

evaluate how their water resources may vary in response to changes in climate (e.g., sea level rise, drought), demand, and sector use, which can then be used to inform policy and to develop strategies to maintain water provisioning in light of different scenarios.

Natural habitats

Healthy forested areas and wetlands help to provide clean drinking water. The U.S. Forest Service (USFS) Forests to Faucets Project[6] uses spatial analyses to identify and map forests that protect critical surface drinking water sources, as well as areas that may be threatened by wildfire, insect and disease outbreaks, and development. For example, forests in the Southern Appalachian Mountains are critical for drinking water, but are vulnerable to increasing development pressures. The Forests to Faucets maps help managers identify key areas for protection and restoration.

The Managing Forests for Increased Water Yield project examines forestland management in north central Florida as a way to retain more water (McLaughlin, Kaplan, and Cohen 2013). Most forest management and land acquisition projects focus on restoration to historic states to help with wildfire prevention and increased biodiversity, yet these traditional management practices support higher forest densities, which also increase water use as more biomass leads to higher water consumption. Studies show that management practices that reduce biomass contribute to increased water storage since less water is lost by evapotranspiration. Since evapotranspiration results in the loss of water for ecosystems, a small reduction of evapotranspiration in managed lands can result in increased ecosystem water storage capacity. By managing forests and conservation lands differently and reducing biomass, we may be able to store more water in forests. This is especially important with increased temperature, changes in precipitation, and increased water demands in the Southeast region. Restoring areas with widely spaced trees will lead to increased water storage in the area. Timber areas that might be purchased for restoration could also be managed with reduced biomass with widely spaced long leaf pines. In any case, timber production uses less water compared to other uses such as farming.

Headwater wetlands play a critical role in regulating water quality in coastal areas, but as their value is not well understood by regional communities, they often do not receive adequate protection and are vulnerable to shifting hydrological regimes as a result of land use change. To help improve understanding of how intact headwater wetlands enhance water quality, researchers from Auburn University, with funding from the Mississippi-Alabama Sea Grant Consortium, are studying nutrient retention in four headwater wetlands of Baldwin County, Alabama that exhibit varying degrees of alteration and experience different flow regimes. Preliminary results indicate that headwater wetlands adjacent to urban or semi-urban areas have reduced capacity to filter water due to higher surface flows stemming from urban runoff, which enhances channelization, reduces infiltration and ultimately causes a loss or reduction in wetland extent. This translates to impaired water quality downstream and in the Gulf of Mexico. Project leads are communicating results with regional municipalities to enhance

[6] USFS Forests to Faucets Project: https://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml

appreciation and recognition for the role these wetlands play in maintaining water quality. Moving forward, they are targeting municipalities experiencing rapid growth, as these areas could benefit from the adjustment of land development ordinances to reduce impacts of urbanization on wetland function. Adjusting ordinances and utilizing low-impact development techniques can both maintain wetland water quality function and provide opportunities for attractive, viable urban development with enhanced property values. Data gathered will also be incorporated into current watershed models to enhance their capacity to analyze how processes such as land use change and climate change may affect headwater wetlands and downstream water quality. Currently, headwater wetlands are not adequately represented in hydrological models, so improving these models is a key step in creating tools that can be used by local and regional planners to protect water resources in light of population growth and climate variability.

Municipalities

Graduate researchers at Auburn University have been studying how climate change may affect water resources management and communities across Alabama. In a 2012 collaborative paper, Auburn researchers identified how integrating ENSO climate variability data can improve point-source discharge permitting processes in regional stream networks (Sharma et al. 2012). The National Pollutant Discharge Elimination System (NPDES) bases discharge permits (i.e. allowable pollutant discharge volumes) on streamflow projections; the goal is to release pollutant volumes that will be diluted to below-dangerous levels while simultaneously maximizing wastewater treatment volumes to maintain economic viability. Discharge permit volumes are adjusted based on streamflow, but the NPDES has historically been plagued by uncertainty in low-flow volumes. Auburn researchers documented how low-flow volumes respond to variations in regional climate, such as fluctuations between El Niño and La Niña phases. By integrating ENSO climate data and projected stream responses into the permitting process, managers can predict impending drought and associated low-flow conditions and proactively reduce point-source discharge volumes, such as ammonia-nitrogen discharges from wastewater treatment plants, in order to protect water quality.

Over the past century, coastal Louisiana has been experiencing significant land loss due to a combination of subsidence and sea level rise. The state's 2012 Coastal Master Plan identifies re-initiating natural land-building processes as a key action to enhance coastal resilience, and proposes diverting significant flows (50,000+ cubic feet per second) from the Mississippi River to different deltaic areas to facilitate this process via enhanced sediment delivery (LCPRA 2012). However, there is uncertainty regarding how established wetlands may respond to these new flows, and more information is needed in order to avoid maladaptive action. To address this uncertainty, researchers are investigating sedimentation rates and ecological impacts of enhanced flows in Wax Lake Delta, a model system in southeastern Louisiana. This delta serves as one of the best analogs for proposed diversion sites along the Mississippi River as it receives similar flow volumes. Analyses of this system indicate that the quality of suspended substrate and temperature of incoming flows have significant impacts on wetland ecological function and resultant water quality. The quality of organic matter being delivered affects ecosystem processes, while warmer water temperatures impair wetland metabolic function. These findings have implications for management, primarily that diverting flows earlier in the year when water temperatures are cooler, will minimize risks of hypoxia and other negative metabolic impacts in regional wetlands, helping to maintain water quality while enhancing land-building potential.

Conduct training and planning exercises

Stakeholder engagement through trainings, workshops, and scenario planning exercises can not only provide much needed information but also motivate action and implementation of on-the-ground projects. Conservation and management practitioners need assistance in conceptualizing the range of issues climate change poses, developing or locating needed information to make decisions, and finding other practitioners with whom to interact and engage as adaptation approaches are created.

Trainings and workshops

The USVI Department of Planning and Natural Resources partnered with the NOAA Coral Reef Conservation Program and the Island Green Living Association to host workshops on green building with residents, designers, and builders in St. Croix, St. Thomas, and St. John in 2013-2014. Participants learned about different ways to minimize the effects of development on the natural environment. These trainings built off of the guidance outlined in *Our Islands, Our Future: Guide to Green Building in the USVI* (The FHWGroup 2013). The guidance focuses on three core elements to green design: (1) natural resource protection, (2) water resources management, and (3) energy optimization. Recommendations for best practices included using native vegetation to help stabilize soils and reduce runoff, and using green infrastructure (i.e. porous paving, cistern capture for reuse, rain gardens, rock check dams, swales, retention ponds) to help control stormwater runoff. Recommendations for vegetated buffers included a minimum 25-foot buffer between disturbed soil and the edge of watercourses, a 150-foot buffer from shoreline mean low water, and a buffer of 50-150 feet from the edge of wetlands.

NOAA's Gulf of Mexico Regional Collaboration Team, the Gulf of Mexico Alliance, and the four Gulf of Mexico Sea Grant Programs promote the regional exchange of climate science and best management practices for adaptation and mitigation through facilitating the Climate Community of Practice (CCoP). The CCoP is an annual gathering of Gulf practitioners, including extension, education and outreach professionals and interested community officials. The CCoP aspires to incorporate adaptation strategies in the comprehensive plans of all Gulf Coast communities, and the annual meeting is used to share and develop appropriate mitigation and adaptation strategies, as well as to discuss changes or new developments in regional climate science.[7]

Scenario planning

The Southern Forest Futures Project[8] assessed projected changes in forest habitats between 2010 and 2060 using a range of plausible future scenarios. These scenarios include factors such

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[7] Gulf of Mexico Climate Community of Practice: http://masgc.org/climate-outreach-community-of-practice/summary
[8] USFS Southern Research Station, Southern Forest Futures Project: https://www.srs.fs.usda.gov/futures/summary-report/

as climate change, invasive species, urbanization, and land ownership and use changes. Commissioned by the USFS and Southern Group of State Foresters, the project identified that water availability and quality are strongly influenced by forest extent and health. For example, conversion of forestlands to other uses (i.e. agriculture, urban areas) has resulted in increased pollutant loading and peak flows and reduced base flows in watersheds. As a result, more intense flooding, lower streamflows, decreased water supply, and degraded water quality are of increasing concern. Using the Water Supply Stress Index, the project determined that by 2050, land use change and population growth will increase water stress in the Southeast by 10%. A core finding of the project is that forest conservation and management can help increase water availability and improve water quality.

Researchers at North Carolina State University recently completed an agent-based modeling study to better investigate different societal, environmental, technological, and management interactions and feedbacks on water supply-demand relationships in Raleigh, North Carolina. Integrating various data and models related to population growth, consumer water use behavior (i.e. indoor and outdoor usage), climate scenarios (i.e. wet, average, dry), reservoir storage, and utility drought management strategies, researchers were able to: (1) validate the model's ability to reflect historical water supply, (2) simulate how water supply may vary in response to different changes (e.g., population growth, wet/dry years), and (3) evaluate how various drought management scenarios employed by the utility may affect overall consumer behavior and water supply under different climatic regimes (wet, average, dry). Results from this new modeling framework show that during wet years, consumer behavior does not significantly affect water supply due to the large size of the local reservoir. Comparatively, during dry years, drought conservation mandates by the utility trigger consumer behaviors and responses (e.g., appliance retrofits, reduced lawn watering) that effectively help maintain water supply in the reservoir despite low inflows. This particular model evaluates the sustainability of different water utility management responses to drought conditions under various scenarios, but future model application opportunities include exploring issues related to reduced water demand and utility revenue, utility pricing and consumer response, as well as ecological impacts during low water periods. Overall, this modeling exercise underscores the importance of understanding the dynamic interactions and feedbacks of societal, environmental, technological, and management trends on water supply and demand in order to plan for long-term sustainability of water resources.

Increase/improve public awareness, education, and outreach efforts

This strategy includes increasing and improving the links between climate science, management, conservation, and public awareness. The broader public also needs to be engaged and made aware of the potential ways that climate change may affect the economy, natural resources, livelihoods, health, and well-being. Gaining public buy-in may also increase political and social capital to support climate adaptation action at local, regional, national, and international levels. These efforts are particularly useful in trying to reduce water demand and increase water efficiency and conservation efforts. Examples from our survey include technical notes on climate change in the Caribbean, educational videos from the USACE, and newsletters and neighborhood rain barrel workshops from a water utility in the City of Newport News, Virginia.

Tetra Tech is providing guidance to the Inter-American Development Bank (IDB) to help it assess its vulnerability to climate change. The IDB was looking for guidance on how to incorporate climate change in its operations and investment planning and management, and specifically to better understand how climate change might affect its investments and what sort of information it could provide to help inform and guide its constituents. Tetra Tech developed a series of technical notes, including one specifically for the Caribbean region, that: (1) outlines what types of general climate data are available for use, (2) provides a framework for conducting an internal vulnerability assessment, and (3) compiles climate data, resources and tools specific to the geographic region in question (e.g., Caribbean) (Herron et al. 2016). Tetra Tech has also developed a tiered assessment that the IDB can use to screen for climate risk in its various investments and projects.

The USACE SilverJackets Program, led by individual states, brings together federal agencies (e.g., FEMA, Natural Resources Conservation Service, USGS), state sister agencies, and proactive communities to discuss flood risks and resilience opportunities. These groups meet every six weeks to try to identify common risks and potential collaborative efforts. Several products and tools have been developed as part of this program, and can be used to enhance resilience communication and engagement at the local level. For example, short videos hosted on YouTube are designed to provide brief, targeted information on resilience tools and outreach methods for local officials. This program has been working hard to develop concise, cross-agency messaging around flood risk and general resilience in Kentucky. By merging and aligning goals of different agencies from federal to the local level, employees of those agencies hope to increase coordination and leverage opportunities.

Waterworks, the local water utility for Newport News, Virginia, started a conservation program in the 1980s, which has enjoyed extremely high success in reducing regional water use. For example, single-family home water consumption dropped from 195 gallons per day to 134 gallons per day between 1997 and 2012, and the largest regional water consumer, Anheuser Busch, has reduced its water use by 50%. Voluntary water conservation has been so successful that Waterworks ended up abandoning a reservoir construction project, as conservation has more than met increasing demand. However, the road to achieving sustainable conservation has not been easy. Waterworks discovered that using only volumetric and monetary incentives to reduce water use resulted in an unsustainable cash flow for the utility; consumers reduced their water use, resulting in less revenue, but operational costs for the utility did not decrease. Waterworks has now stabilized its revenue stream via mainly fixed, rather than volumetric, rates and by promoting the holistic value of water rather than simply its monetary value. A steady cash flow allows for continual and updated conservation programming and provides necessary base funds to explore more sustainable treatment and infrastructure options. In addition to its general conservation outreach via newsletters, social media, regional events, and collaboration with the regional conservation initiative HR GREEN,[9] Waterworks also promotes conservation through residential rain barrel workshops. Via partnership with the Newport News Public Works Department and regional Master Gardeners, Waterworks provides rain barrel workshops where participants can learn about water conservation, Waterworks operations, and get detailed information on rain barrel construction, installation, and use. Workshop participants are given a pre-cut rain barrel that has been refurbished from its previous food transportation role, promoting reuse and recycle themes. The rain barrel workshops are aimed at promoting the use of natural water for outdoor landscaping needs, rather than using treated water that costs both the utility and the customer money.

Create/enhance resources and tools

Resources and tools can enable adaptation planning and implementation. These resources and tools include those that deal with guidance and decision support, modeling and analysis, and mapping. These tools can help managers and other practitioners identify priority resources, assess risk and vulnerability in different sectors, generate other resources to support implementation, and engage with other like-minded practitioners.

Guidance and decision support

Guidance and decision support tools are being developed and used to inform decisions by farmers, water utilities, resource managers, and dam operators. The Southwest Soil and Water Conservation District, Puerto Rico Department of Agriculture, Puerto Rico Land Authority, and the USDA Natural Resources Conservation Service created the Climate Change Adaptation Measures in Southwestern Puerto Rico Project to help improve the Lajas Valley Irrigation System (NRCS 2016). Lajas Valley is the driest region in Puerto Rico and water quantity and quality are major concerns for residents and farmers. The existing irrigation system was built in the mid-1950s to provide supplemental irrigation water to nearby agricultural lands. The partners are working to develop tools to assist local farmers in identifying how much water is needed for optimal soil moisture during different seasons, which will help with water conservation efforts.

Peace River Manasota Regional Water Supply Authority supplies water to over 300,000 people in southwest Florida. The Authority is looking at water banking from the Peace River and storage in Aquifer Storage and Recovery (ASR) wells to be used during dry seasons. The key question managers struggle with is how to manage for a climate-resilient water supply, when to manage for drought, and how to manage wet years in the most efficient and cost-effective way possible. This effort examined projected river flow forecasts under current water supply and demand scenarios along with climatological forecasts to determine when water managers should start ASR storage. The Authority currently relies on water supply from the Peace River, which is rainfall dependent. When there are high precipitation events, the Authority stores water into two large reservoirs; water can also be captured and stored into ASR wells. The wells can store almost as much water as the reservoirs (i.e. six billion gallons of water), but recovering water from them takes more time and requires spending money on reverse osmosis

[9] Hampton Roads Planning District Commission, HR GREEN: http://askhrgreen.org

treatment to meet drinking water standards. The Authority developed an index as a decision support tool to determine when to start ASR wells (Morris 2013). It was developed in Excel as a simple, zero-order additive function considering 10 different elements: raw water reserves, river flow, month, three-month precipitation forecast, Keetch Byram Drought Index (KBDI), one-month precipitation forecast, ASR reserves, three-month temperature forecasts, demands, and one-month temp forecast. If the weighted factors result in an index value of 1.0 or above, that reflects a need for ASR recovery operations. As drought increases in intensity and duration, managers will need to respond to regional water demand.

The USDA Southern Research Station and the Virginia Tech Conservation Management Institute developed and are in a trial testing period for the Crossing Assessment Decision Support System (CADSS). CADSS is a suite of tools that combines data and user-defined criteria to help managers prioritize road-stream crossing replacements in order to increase fish passage and improve stream and fish habitat connectivity. CADDS utilizes two separate component tools: the Watershed Prioritization Tool (WPT), which analyzes watershed data (e.g., land ownership, species distributions, stream mileage, density of road crossings) to locate high priority watersheds for fish passage improvement projects, and the Crossing Replacement Tool (CRT), which individually analyzes the selected high priority watersheds and identifies which road-stream crossings will provide maximum benefits if replaced. CADSS also allows users to define their search criteria. For example, managers can choose to only analyze watersheds on federal or private lands, respectively. In the future, developers hope CADSS can be applied to any watershed, provided that the necessary geographic, biological, and physical data (e.g., road-stream crossing points, species distributions, flow data, etc.) is available. In addition, developers believe climate change data could be integrated as a future module in CADSS. For example, species vulnerability data or shifting flow regime projections could be incorporated at the watershed level and used as another layer for identifying priority watersheds for management projects. Integrating climate change layers and prioritizing key habitats under changing conditions could be a crucial management strategy for species facing large-scale habitat loss in the Southeast, such as the brook trout.[10]

In collaboration with Tennessee Technical University, the Tennessee Valley Authority, and the U.S. Fish and Wildlife Service (USFWS), the USGS Tennessee Cooperative Fisheries Unit completed a structured decision-making (SDM) model for dam managers at the Tims Ford Dam on the Elk River,[11] and a project focused on SDM model implementation and optimization.[12] The Tims Ford Dam SDM model aims to facilitate adaptive dam management and achieve three goals: (1) reduce negative impacts of cold water release on imperiled native, warm water species, allowing for species persistence and expanded distribution, (2) protect freshwater habitat for important recreational sport fish species (e.g., trout, bass), and (3) maintain the hydropower and flood protection services provided by current dam infrastructure. Based a

[10] USFS Southern Research Station, Crossing Assessment Decision Support System: http://www.srs.fs.usda.gov/catt/cadss.html
[11] Tennessee Cooperative Research Unit, Building a Structured Decision Making Model for the Elk River: http://www.coopunits.org//Tennessee/Research/Completed/6.9215105024E10
[12] Tennessee Cooperative Research Unit, Implementing and Optimizing a Structured Decision Making Model for Regulated Rivers: https://www.coopunits.org/Tennessee/Research/Completed/7.6897533952E10

variety of input factors, including season, flow patterns, hydropower needs, aquatic species life history and river distributions, the SDM model suggests appropriate dam management actions. For example, based on daily conditions and known species occurrences, the SDM model outlines when, how, and how much water to release from Tims Ford Dam. Development and future implementation of this model represents a new partnership between historically at-odds groups; regional dam and wildlife managers will now be able work together towards protecting the interests of both human and natural aquatic communities. If successful, researchers hope that unique SDM models will be developed and used for all dams within Tennessee, becoming the basis of future dam management. In addition, researchers hope that climate change data (e.g., changing hydrological regimes) can be integrated into future models.

Modeling and analysis
The USACE is in the process of learning how to use climate science to influence and improve water policy and management. Since 2009, the USACE has conducted 15 climate change adaptation pilot studies around the country, including a study on collaborative water management in the Ohio River Basin. These pilot studies had three goals: (1) to better understand how USACE water management decisions are currently being made, (2) to identify where climate change and climate science can be incorporated into the decision making process, and (3) to use that information to develop and/or shape the generation of new climate change data that can be integrated into engineering frameworks. Current climate data has limited usefulness in engineering contexts, so the USACE hopes to better articulate the type of climate data it needs. For example, the USACE has engaged with regional researchers and other federal agencies to better understand and downscale drought and downpour projections and potential impacts on local operating procedures. In addition, the USACE is helping with the Coupled Model Intercomparison Project[13] in collaboration with other public and private entities. The CMIP integrates IPCC data and creates different scale models of climate change data, which the USACE hopes to use to explore how projected climate changes could impact its decision and management frameworks in different localities.

Drought Forecasting for Small to Mid-sized Communities of the Southeast United States analyzes the impacts of the ENSO on regional precipitation and streamflow patterns and develops a Community Water Deficit Index (CWDI) for drought forecasting for small and mid-size communities (Sharda 2012). The CWDI links water supply – based on regional climate trends and variability – with public water demand in order to calculate drought risk, an approach that can be used proactively to minimize drought vulnerability of community water systems. For example, warm and dry winter phases associated with La Niña cycles typically correspond with higher water demand by the public; water resource managers could recognize and proactively plan for these high demand periods using the CWDI, implementing water allocation limits, conservation mandates, or other climate-informed water initiatives. By developing and analyzing the usefulness of regional climate data and a new small-scale drought-forecasting tool, this study hopes to help regional water resource managers incorporate ENSO-derived climate variability into decision-making processes.

[13] Coupled Model Intercomparison Project: http://cmip-pcmdi.llnl.gov

Mapping

The Century Commission for Sustainable Florida undertook the Critical Lands and Waters Identification Project (CLIP),[14] a large mapping effort, in 2006 to identify lands and waters that were critical for conservation. The CLIP database is a thorough collection of spatial data that for including biodiversity, landscapes, surface water, groundwater, and marine resources. Once completed, it was clear that CLIP should also include future climate conditions to enable prioritization of critical lands for conservation and acquisition. The Century Commission recently incorporated sea level rise, urbanization, and policy scenarios into CLIP to support landscape-scale conservation planning and decision-making by entities such as the Peninsular Florida Landscape Conservation Cooperative.

The Georgia coast is very vulnerable to sea level rise and geospatial tools are needed to help managers prepare for coastal hazards. The Georgia Coastal Hazards Portal was developed to help perform regional evaluations of coastal hazard vulnerability. The goal of this project is to develop an accessible geospatial tool that can be easily used by coastal managers and scientists using the best available data, which addresses both vulnerability and hazards to the region. To develop the tool, the project team undertook an extensive literature review, collected shoreline databases from various sources from coastal survey maps and orthophotos as well as socioeconomic data. Along with the shoreline database, GIS tools were built to perform shoreline analysis of multiple hazards, leveraging existing data incorporating both natural and social vulnerabilities using ArcGIS and R statistical computing. During 2012 and 2013, various workshops were conducted to train costal managers on how to use this tool to better prepare for coastal changes in the future.

Kentucky is known as water-rich state, but it has experienced 35 disaster declarations since 2000, 32 of which have been flood-related. To improve resilience to flood events as well as to enhance general social, economic, and environmental resilience, the state has engaged in a risk mapping initiative. RiskMap takes flood hazard mapping to new heights by helping communities integrate flood risk with local hazard mitigation planning. RiskMap helps communities identify flood risk related to various flood characteristics (e.g., depth, flow rate), examine various evacuation routes, and draw connections between infrastructure improvements and reduced flood risk, which can inform local hazard mitigation planning. Through enhanced mapping and visualization, RiskMap highlights how investing in resilient infrastructure benefits communities in the long term. Although this program allows communities to analyze various-sized flood events, there are hopes to incorporate climate change into the model in the future by integrating different storm and development scenarios and analyzing how they affect flood recurrence intervals and magnitudes.

Monitor environmental and climatic conditions and adaptation effectiveness

Monitoring can help practitioners track environmental changes and identify needed modifications in applied management strategies. It may be used to demonstrate correlations between climatic and environmental changes, assess climate change impacts on habitats and

[14] Critical Lands and Waters Identification Project (CLIP): http://www.fnai.org/clip.cfm

species, provide early warning signals that may indicate a need for management interventions, and evaluate the effectiveness of adaptation action. Several regional efforts have focused on monitoring environmental and climatic change, but to date there is an overall lack of evaluation of effectiveness of action.

Kentucky Sanitation District No. 1 (KSD No. 1) is utilizing a watershed management approach[15] to manage stormwater and wastewater for three county areas in Northern Kentucky. Through extensive biological, hydromodification, and water quality monitoring of regional streams, KSD No. 1 has determined that small storm events (e.g., two-year flood events) are having a significant impact on stream channel form, water quality, and aquatic biological communities, likely due to enhanced runoff and erosion resulting from increased impervious surface area. Enhanced runoff also has implications for the utility's combined wastewater and stormwater sewer system, as higher runoff increases the likelihood of sewer overflows, which can endanger public health.

The Gulf Restoration Network also strives to improve water quality and protect wetlands. Its Healthy Water Initiative works with the Federal Government and states in the Mississippi River Basin via the Mississippi River Collaborative to enact policies that reduce water-borne pollutants contributing to the Gulf of Mexico dead zone. These cleanup policies are especially important in light of climate change and shifting flow regimes, as shifting flow regimes make the annual size of the dead zone increasingly hard to predict. Higher flows as a result of flashier storms and more intense downpours can carry more pollutants and increase the size of the dead zone, while drought periods and low flows shrink the size of the dead zone, but can be used to analyze legacy pollution. In addition, the Gulf Restoration Network monitors wetland destruction and discharge permits granted by the state and USACE to ensure that permittees abide by the Clean Water Act and that all wetland destruction is mitigated to avoid net loss of wetlands and loss of wetland function. However, the Gulf Restoration Network is concerned that these permits (e.g., discharge volumes) are not adjustable based on shifting flow regimes, which could have serious consequences for regional water quality in the future.

The Jean Lafitte National Historic Park and Preserve has recently engaged in an extensive freshwater monitoring program to enhance understanding of how park hydrology is changing as a result of sea level rise and subsidence. The park actively monitors 28 wells, and is beginning to implement a variety of surface elevation and dynamic tools to better understand how hydrology and land surfaces are changing at a landscape scale. The park hopes to combine this monitoring data with high quality regional climate modeling to better understand how park resources may change in the future, which will inform sustainable resource stewardship and management.

Scientists from the University of North Carolina Chapel Hill are investigating how various rainfall and storm events affect stormwater and water-borne pollution movement at several North

[15] Sanitation District No. 1 of Northern Kentucky, Watershed Management: http://www.sd1.org/ProjectsandPrograms/WatershedManagement.aspx

Carolina beaches. Via extensive monitoring during storm periods, the research team is attempting to better understand the fate and transport of stormwater once it enters the ocean and its impact on overall water quality. This information is being integrated into a predictive model that will help analyze how various storm types are likely to affect public health risk. Although not designed to address climate risk, specifically, by studying a variety of storm events, the researchers are gathering valuable data about how climate variability affects water quality. The researchers hope this research can help inform public policy to both better protect public health and to minimize negative impacts of storm events on beach economies. By better understanding where and for how long pollutants exist after a given storm event, clearer and more specific beach signage and advisories can be issued to ensure that users don't recreate in potentially hazardous waters. In addition, this research can help minimize beach closure or advisory durations, thereby minimizing storm-related closure effects on local beach economies.

The Bald Head Island Conservancy is engaged in an ongoing monitoring program to better understand aquifer water supply and quality trends on Bald Head Island off the coast of North Carolina. The Conservancy is monitoring total dissolved solids, pH, and salinity in 40 different wells and several surface ponds. Current data indicate that water supply is lowest during summer tourism months, while recharge occurs during the winter wet season. Saltwater intrusion has been documented in some outer wells, and may be correlated with channel dredging activity. Through continued monitoring, and as its USGS partners complete a hydrogeological mapping framework of the aquifer, the Conservancy hopes to better understand water supply and quality trends, which can inform sustainable water resources management for the island community in the future. Baseline hydrologic data will be important, particularly given potential impacts of sea level rise, and as human development on the island increases. This monitoring project is housed within a large island effort to engage in long-term strategic planning and encourage actions that promote sustainable barrier island living, including practicing water conservation and planting native vegetation.

The Coastal Carolinas Drought Early Warning System[16] is a stakeholder-led project to help the region prepare for drought. The program focuses on the coastal ecosystems in North and South Carolina, and impacts on water quality and water quantity, as well as drought impacts on habitats, species, and ecosystems. Project partners include the Carolinas Integrated Sciences and Assessments, Southeast Climate Science Center, South Atlantic Landscape Conservation Cooperative, USDA Southeast Climate Hub, National Drought Mitigation Center, State Climate Office of North Carolina, and the South Carolina State Climatology Office. Team members are developing citizen science monitoring network to document the effects of rainfall and drought on local environments (Community Collaborative Rain, Hail, and Snow [CoCoRaHS]), and the creation of a Coastal Drought Index to characterize environmental conditions and inform decision making.

[16] Coastal Carolinas Drought Early Warning System: http://www.drought.gov/drought/regional-programs/coastalcarolinas/dews-coastal-carolinas-home

Policy

Mainstreaming adaptation into policies and plans is a key mechanism for adequately responding to climate change impacts. Example strategies within this category include developing adaptation and drought mitigation plans, creating new or enhancing existing policies, and developing adaptive management strategies.

Develop/implement adaptation plans

Adaptation plans typically assess likely climate change impacts, identify goals and measures to build adaptive capacity and limit vulnerability, and establish guidelines to support the implementation of adaptation actions. Governments play important roles in climate change adaptation by coordinating and mandating action at the state, regional, county, and city level.

State adaptation planning

In 2008, the Adaptation Working Group of the Virginia Governor's Commission on Climate Change published a Climate Change Action Plan. This plan analyzed climate trends and provided recommendations for the best management actions, research needs, and policy changes related to climate change and sea level rise within the state. Freshwater resources management was a component of this report, and both impacts and potential management options were analyzed for a variety of water resources, including drinking water, water supply, freshwater habitats, and stormwater. For example, the report identified saltwater intrusion and variable precipitation patterns as the main dangers to Virginia's water supply, and it recommended that the State Water Control Board amend the comprehensive water supply planning regulation to require local and regional planning agencies to consider climate change impacts on existing and proposed water supplies. For stormwater issues, the report recommended improving stormwater system capacities in order to improve management of larger stormwater flow volumes. For freshwater flow maintenance, the plan recommended that the State amend water-permitting processes to account for shifts in flow regime. Implementation of these and other suggested adaptive management actions started in 2009, but unfortunately, a change in governance halted climate change adaptation advocacy and action at the state level through 2013, though many local initiatives were active during this period.

Regional adaptation planning

The Southeast Florida Regional Climate Action Plan is a product of the Southeast Florida Regional Climate Change Compact, a collaborative effort among four counties in southeast Florida – Palm Beach, Broward, Miami-Dade, and Monroe – that identifies regional climate impacts of concern and mitigation, adaptation, and resilience initiatives (SFRCCCC 2012). The plan aims to integrate climate adaptation and mitigation into existing policies and contains 110 priority action items to be accomplished. The impacts of climate change on water supply, management, and infrastructure in Southeast Florida are clearly identified, with drier winter and spring months resulting in an increase in local evapotranspiration, increased drought periods, and less frequent but more intense storms, causing both inland and coastal flooding. These impacts are all compounded by sea level rise and saltwater intrusion. The plan includes

18 strategies to advance water management and infrastructure improvements; key strategies include:

- Develop local and regional inventories of potable water storage and conveyance systems, wastewater infrastructure, septic tanks, and stormwater drainage and treatment facilities, and develop adaptation strategies for high-risk systems;
- Identify areas and infrastructure at increased risk of flooding and tidal inundation;
- Coordinate with the South Florida Water Management District and others to identify water resources infrastructure already operating below standards;
- Manage natural water carrying capacity and storage publicly owned upland and wetland habitats; and
- Support implementation and funding for the Comprehensive Everglades Restoration Plan to ensure freshwater storage and aquifer recharge.

The Southeast Florida Regional Climate Change Compact hopes the plan will provide a framework that will stimulate the creation of a stronger and more resilient Southeast Florida in the future.

County adaptation planning

Lee County, Florida, conducted a vulnerability assessment and adaptation planning project in conjunction with the Southwest Florida Regional Planning Council in 2010 (Beever et al. 2010). The project included an assessment of regional climate change impacts and potential resilience strategies. The most significant impacts identified include changes in hydrology, intensity and severity of storms, sea level rise, increasing water temperature, and ocean acidification. The county identified 125 potential strategies for incorporation into the comprehensive plan in collaboration with government officials from 39 county departments and divisions. The Lee County Climate Change Resiliency Strategy identifies several water-related strategies, including adopting nature-based coastal defenses, elevating water resources infrastructure, implementing green infrastructure, limiting groundwater extraction, encouraging agricultural water reuse, acquiring land for flood and water supply, building climate-friendly landscaping into codes, charging more for treated water, and engaging in drought preparedness efforts. The study also includes recommendations on how the resiliency strategies can be integrated into comprehensive plans.

The Model Forest Policy Program created the Climate Solutions University[17] to help communities create adaptation plans. The process includes four steps:

1. Local communities create stakeholder action teams.
2. Teams assess vulnerabilities and opportunities for action.
3. Teams develop actionable adaptation strategies.
4. Strategies are implemented and evaluated.

Three communities participated in Climate Solutions University, including Rockingham County, North Carolina; and Greene County and Sumner County, Tennessee. Rockingham County, with leadership from the Dan River Basin Association, examined the vulnerability of local forest and river resources and economic interests to extreme weather events, and outlined potential

[17] Model Forest Policy Program, Climate Solutions University: http://www.mfpp.org/csu

adaptation options to increase resilience. The final plan prioritizes actions, outlines a work plan for the first year, and discusses capacity and resources needed for implementation. Priority actions included reducing sediment loading into important rivers, planting riparian buffers, and increasing water quality monitoring. The plan was published in 2012, but unfortunately, there has been limited implementation since its publication (Edwards et al. 2012).

The Cumberland River Compact (CRC) and the Middle Nolichucky Watershed Alliance created a climate adaptation plan for Greene County (Nissely et al. 2011). The plan includes an analysis of local climate change impacts, risk assessments for county water, forest, and economic resources, and identifies opportunities for mitigating risk. In addition, it includes an implementation strategy, which establishes specific, measurable goals for five-year (medium-term) and twenty-five year (long-term) time frames, lays out specific objectives and component actions to help achieve those goals, and identifies which groups are responsible for implementing different actions. For example, key goals related to water resources include: protecting water quality by increasing riparian zones by 50% in five years and by 85% by 25 years; and lessening the severity of flood events by developing away from floodplains and encouraging low impact development and green infrastructure. Specific actions to achieve riparian goals include cataloging and mapping current riparian zones, mapping future projected changes, identifying priority conservation riparian zones, training community members in streamside survey methods, and engaging the public in restoration efforts, among others. Each action has an appointed lead – either an organization or individual – as well as a target completion date.

In 2010, the CRC and Sumner County established a Natural Resources Protection Working Group to create a climate adaptation plan (Briggs et al. 2010) that advances the natural resource and resilience goals of the county's 2035 Comprehensive Plan (SCRPC 2010). The adaptation plan examines the current state of Sumner County's forest and water resources and analyzes current and projected climate change and population growth impacts on those resources and the local economy. For example, the plan identifies increasing runoff, development, flooding, and water demand as the main risks to the county's water resources. The plan also identifies measurable medium- and long-term goals with specific action items that can be used to mitigate impacts on forest and water resources. For example, the county prioritized protecting headwater streams and the health of water resources as a both medium- and long-term goals, and the plan identifies a variety of actions that can be taken to achieve these goals, as well as identifying who will be responsible for each action and establishing timeframes for completion. For example, rain water harvesting, zoning changes to reduce flood risk, green infrastructure installation, and establishing a river monitoring network are all specific actions presented in the plan that will be used to make the county's water resources more resilient to climate change impacts.

City adaptation planning
The City of Alexandria, Virginia approved the Energy and Climate Change Action Plan 2012-2020 (ECAP) on May 14, 2011 (City of Alexandria 2011). The plan builds on the existing Eco-City

Charter and Environmental Action Plan 2030 (EAP) by providing information on policies and measures that the city is already undertaking as well as new policies to achieve climate reduction goals. The ECAP identifies decreased water availability as a challenge to both the region's economy and natural systems, and sea level rise and increased hurricane intensity as major causes of future property damage and associated coastal flooding. The plan includes goals to reduce water demand, improve water use efficiency, expand and diversify water supply, and increase drought preparedness by taking actions, such as:

- Modifying building codes to require low-flow plumbing or other water conservation measures;
- Providing incentives for water efficient processes and appliances;
- Promoting best management practices for stormwater (e.g., rain barrels, rain gardens);
- Coordinating with regional water authorities on surface and groundwater supply and storage;
- Updating drought management plans to incorporate climate change;
- Moving or abandoning infrastructure in vulnerable areas;
- Discouraging development in vulnerable areas; and
- Requiring separate sewer and stormwater infrastructure as a condition of approval and permitting for new development and redevelopment.

The Tybee Island City Council voted unanimously in April 2016 to approve a sea level rise adaptation plan (Evans et al. 2016). Tybee Island is a low-lying barrier island that attracts significant numbers of tourists annually. The island is vulnerable to frequent flooding events, which are projected to become more frequent and intense with severe storms and sea level rise. Working with Georgia Sea Grant and the University of Georgia, the city identified areas that are most vulnerable to projected increases in sea level. Key water-related strategies recommended in the plan include:

- Using living shorelines to stabilize shorelines rather than sea walls and bulkheads;
- Retrofitting the stormwater drainage system with water control structures to help reduce local flooding and saltwater intrusion; and
- Elevating critical infrastructure, including well pumps and wastewater lift stations.

The plan is the first sea level rise plan developed in Georgia and has been studied as an example for similar processes in other Southeast communities, including St. Marys, Georgia; Hyde County, North Carolina; and Monroe County, Florida.

In 2007, the Charleston City Council established the Green Committee to develop a local sustainability and action plan on climate change. The committee, comprising business, academic, nonprofit, and government leaders, developed the Charleston Green Plan in 2009 to help the City of Charleston move toward a more sustainable future (Charleston Green Committee 2009). The plan identifies key climate impacts of concern to the city, including changes to ecosystems, water scarcity, increased heat stress, and sea level rise. It aims to increase the city's sustainability through six major efforts: better buildings to reduce energy costs, cleaner energy using renewable energy sources and reducing CO_2 emissions, sustainable communities that address sea level rise and future growth, improved transportation through efficiency and increased public transportation measures, zero waste by increasing recycling and water conservation, and green education to help ensure success and meet the plan's goals. The city established a Sustainability Advisory Committee to oversee the plan's implementation. The committee advised the City Council to adopt the 2015 Sea Level Rise Strategy, which requires planning for 1.5-2.5 feet of sea level rise over the next fifty years (City of Charleston 2015). Specific actions include designing water retention systems, improving stormwater drainage, and using green infrastructure.

The City of Pompano Beach Water Utility and the Florida Atlantic University's Center for Environmental Studies partnered on a project to assess the city's vulnerability to climate change and develop potential adaptation strategies to protect freshwater supply, prevent flooding, maintain drainage systems, protect ecosystems, and prevent economic losses (Bloetscher, Meeroff, and Heimlich 2010). The city is currently experiencing water shortages during times of drought, stormwater flooding in coastal low-lying areas, saltwater contamination of groundwater, and a higher water table, all of which will only be exacerbated in a changing climate. In addition, the city may also be affected by more intense storms, which may uproot trees, damaging water pipes and causing more coastal flooding. Near-term (by 2030) strategies include eliminating trees in rights of way to avoid storm damage, upgrading water plant equipment, encouraging water conservation, and repairing and upgrading sewer systems. Mid-term solutions (2040-2070) include reusing wastewater for irrigation, using reclaimed water to recharge the aquifer, treating brackish water for drinking water supply, installing more pumps to prevent flooding, replacing ineffective septic systems, closing private irrigation wells to conserve water, and installing salinity control structures. Long-term solutions (2070-2100) include injecting reclaimed wastewater into brackish aquifers, implementing major renovations of flood control systems, discharging excess water into the Everglades, preparing for low-lying areas to be abandoned, and implementing a large-scale system of dikes.

Develop/implement drought mitigation plans

Drought mitigation and response plans identify mechanisms for governments and other entities to monitor, mitigate, and respond to drought. Taking actions to prepare for and respond to drought can help reduce associated long-term risks. Examples from our survey include plans from state and city entities.

State drought mitigation and response planning

In 2008, the State of Kentucky adopted a Drought Mitigation and Response Plan to better coordinate state and federal communication and action around drought issues. Kentucky periodically experiences moderate to severe droughts, and the state had need of a definitive plan on how to characterize and respond to such events. The plan was developed with input from the Drought Mitigation Council, a stakeholder working group comprised of 50-60 individuals. Key aspects of the plan call for enhanced drought monitoring (e.g., enhance stream gauge network, develop a groundwater monitoring network), the identification of water supply development opportunities, and a clear outline of drought response measures and responsibilities. This plan was used in 2010 and 2012 during drought periods, and helped reduce decision-making paralysis. Future updates to the plan will likely include a more extensive look at agricultural versus hydrological drought, and may include development of agricultural drought monitoring metrics and responses.

The Division of Water Resources in North Carolina is involved in a variety of projects aimed at maintaining water supply and quality for both humans and natural communities. DWR is working with various water systems to develop drought response plans. Water systems are required to submit information related to usage, withdrawals, and discharges, and to project water demand 30-40 years in the future. The department compares this data to its own models of future water supply and demand, and then helps water suppliers adapt a boiler-plate, state-provided drought response plan to fit their particular system and conditions. These plans typically set thresholds that trigger reduced usage as drought conditions progress.

The Alabama Department of Economic and Community Affairs Office of Water Resources (OWR) is actively involved in developing and updating the state's Drought Management Plan. The original Drought Management Plan was developed in 2004, and focused on streamlining communication and coordination between water managers and users in response to drought conditions. The historic drought period from late 2006 though early 2008 allowed the OWR to test the effectiveness of its plan, and it has since been developing ideas and updates to improve that plan. For example, the OWR is in the process of developing a more rigorous state-based drought monitor, which will incorporate short- and long-term drought forecasting capabilities in addition to the real-time data provided by the national U.S. Drought Monitor. The forecasting data will be generated from a variety of sources, including trends in water availability, trends and changes in water demand (e.g., population growth or changes in sector use), local climatological conditions, and short- and long-term climate projections. By creating a state-based drought monitor with forecasting capabilities, the OWR hopes to provide water managers and users with a more holistic picture of water supply and risk. Development of a state-based drought monitor is just one component of larger drought planning activities across Alabama. For example, the 2013 revision of the Alabama Drought Management Plan includes a more specific outline of drought triggers, clarifies different inter-agency roles during drought periods, and continues to promote collaboration and communication between water managers and users (ADECA 2013). In addition, the Alabama Drought Planning and Response Act was signed into law on April 9, 2014, detailing the state government's role in planning, monitoring, and responding to drought conditions. This act formally establishes the Alabama Drought Assessment and Planning Team (ADAPT) and the Monitoring and Impact Group (MIG), requires all public water systems within Alabama to create water conservation plans, improves protocols and requirements for reporting local conditions and water supply, and clarifies how the OWR will issue drought declarations. The Alabama Drought Planning and Response Act allows collaborative discussion and development of regulations surrounding drought, and ensures that state-based drought planning procedures can be easily integrated into comprehensive statewide water resources planning.

City drought mitigation and response planning

The Town of Cary, North Carolina developed a Water Shortage Response Plan to be activated during periods of acute or chronic water shortages. This plan includes a hydrologic modeling demonstration, demonstrating that in a severe water shortage scenario (i.e. where reservoir inflows to the main water source, Jordan Lake, decreased by 36%), implementing its water shortage response plan would allow the Town to maintain 50% of its water storage. By comparison, if there were no water shortage plan in place, the same conditions would mean that all available water was consumed, resulting in a water crisis.

Create new or enhance existing policies or regulations

Legislation and regulation can mandate action on climate change. Decision makers, managers, and planners may choose to create new frameworks or opt to use existing frameworks within which to support conservation and management efforts. Creating new policies can be both timely and costly, but may be required if the existing structure is lacking. Incorporating future climatic changes and impacts into existing policies and plans involves examining existing policies and considering how desired outcomes may be affected as the climate changes. This includes policies regarding critical species and habitats, water flows, water reuse and recycling, and water rights and usage.

Critical species and habitats

The Arkansas Wildlife Action Plan helps guide the identification and management of key species of greatest conservation need (Fowler 2015). The initial plan was approved by the USFWS in January 2007, and revised in January 2015. The initial plan did not include consideration of climate change impacts. Climate change was integrated into the revision using guidance from the Association of Fish and Wildlife Agencies (AFWA 2009). An entire chapter is dedicated to climate change in the revised plan, providing an overview of climate science and projected impacts on Arkansas's habitats and species, and an adaptation strategy. The project team used The Nature Conservancy's ClimateWizard to project changes in mean temperature and precipitation out to 2070. Habitats that may benefit from increased temperatures and drier conditions in Arkansas include glades and barrens, dry upland forest, and open woodlands/savannas, while these same conditions would put mesic forests, wetlands, and streams at risk. The plan identifies several goals and objectives to reduce vulnerability that closely match those recommended in the National Fish, Wildlife, and Plants Climate Adaptation Strategy. Core priorities include restoring and maintaining habitats, protecting key habitats, increasing adaptive management capacity, and monitoring the response of species and habitats to climate change. Actions identified in the plan include protecting climate refugia for species, creating a network of protected lands, cooperating with surrounding Landscape Conservation Cooperatives and Climate Science Centers on climate-informed conservation data and tools, and conducting vulnerability assessments for selected habitats and species as funds become available.

Water flows

North Carolina's Division of Water Resources has completed a preliminary analysis of how various streamflows affect ecological communities, and have used this information to inform ecological flow planning and recommendations in various basins. Most recommendations attempt to maintain 80-90% of natural streamflow at any given point and/or use threshold points (e.g., a 5-10% change in the ecological community/population) to trigger different management actions. These flow recommendations will help maintain the ecological viability of streams in the face of population growth, increased water withdrawals, and increasing climate variability. Proposed flow recommendations are currently under review and revision by the Environmental Management Commission. The department is also attempting to integrate instream flow requirements into other planning and permitting activities (e.g., site-specific project planning, dam safety permitting and relicensing).

Water reuse and recycling

The City of Mobile, Alabama is exploring how green infrastructure can be integrated into its historic urban landscape to address stormwater issues and increase water recycling. The design firm 2D Studio headed a project called Greenstreets Mobile[18] to demonstrate how existing infrastructure, streetscapes, parks, and vacant lots could be redesigned to maximize aesthetic and stormwater retention benefits for the city. For example, the master plan proposed installing stormwater planters that would capture street runoff and elevated cisterns that would collect and store stormwater from rooftops. These cisterns could be used to fill city water trucks and irrigate horticultural display baskets to beautify the historic district. In addition, the plan proposed an extensive water re-use system that includes a surface water treatment pond with aquatic plants, a settling tank, a storage tank, and water wall to purify stormwater. Once cleansed, this waste could be used to irrigate vegetation in a renovated public courtyard.

In partnership with UNC Chapel Hill, the Orange Water and Sewer Authority (OWSA) designed, constructed and launched a reclaimed water system, which began operations in 2009. This reclaimed water system now meets more than 10% of current water demand. In addition, the reclaimed water plant itself is resilient to climate change impacts. During the design and construction process, OWSA and partners knew that the plant needed to be elevated (at minimum) to withstand a 100-year flood event. However, given their recognition of increasing climate variability and the potential for increased flood volumes, they elected to elevate the plant even higher in order to enhance its long-term resilience. By building climate resilience into the design and construction phases of the project, OWSA implemented a low-cost adaptation strategy that will help maintain water supply resilience and reliability under a variety of future climate conditions.

Water rights and usage

Louisiana Sea Grant is in the midst of developing a comprehensive State Water Law for Louisiana. Louisiana has a long history of sharing water with other states (e.g., the Red River

[18] Greenstreets Mobile: http://www.2dstudiollc.com/projects/greenstreets-mobile-alabama

Compact with Texas), but water rights and water usage are becoming pressing topics in the face of climate change and growing populations. Louisiana Sea Grant believes that the state needs a long-term plan to both ensure sustainable management of available water and to protect water resources from being unfairly exploited by neighboring states. The proposed State Water Law will attempt to describe and give value to Louisiana's water resources, describe critical management strategies, and describe how future climate change factors (e.g., altered rainfall patterns, flashier storms) can affect water resources management. Louisiana Sea Grant hopes to pass this water legislation as soon as possible, and is currently developing model legislation for comprehensive water policy and conducting outreach via the newly established Water Resources Commission. Through drafting and enforcing a statewide Water Law, Louisiana Sea Grant hopes to protect Louisiana's freshwater resources both now and in the future and help communities and government prepare for the impacts of climate change.

The Catawaba-Wateree Water Management Group (CWWMG) was incorporated as a non-profit organization in 2007 to help redesign management strategies to meet future water supply needs for human consumption, power production, industry, and agriculture in the region. Studies have shown that, if managed the same way, by 2050 the Catawaba-Wateree Basin's reservoir yield would be unsustainable. The CWWMG consist of 19 members representing 18 public water utilities in North and South Carolina that operate intakes along the Catawaba-Wateree Basin and one representing Duke Energy. The CWWMG updated long-term water use projections, and developed conservation strategies to meet future water needs and improve drought management throughout the basin. The Water Supply Master Plan includes the potential impacts of climate change on the basin's water supply and modeling future water withdrawals and return projections to 2065 (CWWMG 2014). The plan evaluates 26 future operating scenarios in eight main categories: population growth sensitivity, climate change sensitivity, public water efficiency measures, power industry consumptive water use changes, critical intake modifications, effluent flow recycling, modified reservoir operations, and low inflow protocol modifications. The Master Plan modeled impacts on safe yields for integrated scenarios and recommends that the CWWMG adopts the scenario that extends water yields and provides sustainable water supply by implementing water use efficiency techniques in residential and commercial buildings, reducing water withdrawals, and protecting reservoirs.

Develop/implement adaptive management strategies

Adaptive management plays an important role for decision makers looking to overcome the inherent uncertainty of climate change. It is an iterative process, whereby decision makers test hypotheses through monitoring and adjust decisions and actions based on experience and actual changes in order to improve management. This process can either be active (testing multiple options at once to determine the best course of action) or passive (implementing one option and monitoring to determine if adjustments need to be made). Examples from our survey include the R.L. Harris Dam and the Great Dismal Swamp National Wildlife Refuge.

R.L. Harris Dam

The Tallapoosa River in east central Alabama is known for providing a variety of services, including aquatic species habitat provisioning, hydropower production at the R.L. Harris Dam, and recreational boating and fishing opportunities. In response to state and federal concerns about the impacts of hydropower dam operations on downstream aquatic biota (e.g., due to reduced flows, extreme flow variations, and daily temperature changes), a collaborative, stakeholder-driven adaptive management framework was developed for the R.L. Harris Dam.[19] This adaptive management framework was designed to assess how flow management at the R.L. Harris Dam affects various stakeholder objectives on the river, and to utilize a decision support framework and extensive monitoring to inform flow regime and dam management. This process was encouraged as an alternative to a one-time, minimum flow requirement evaluation for the dam, and will likely serve as a key template for relicensing other dams within the region.

Stakeholder engagement and extensive monitoring are two critical components of this project. Stakeholder involvement began in 2002, when all stakeholders with a vested interest in the Tallapoosa River gathered for a workshop, where they identified the top 10 objectives[20] they felt important to maintain along the Tallapoosa River. These objectives, along with current flow data and assumptions about how various flows impact aquatic biota, were integrated into a decision support tool which facilitates evaluation of how various flow regimes affect key objectives in the river basin. Utilizing the decision support tool, stakeholders were able to identify flow recommendations for the dam that would meet a variety of key objectives. These flow guidelines were implemented by the R.L. Harris Dam in 2005, and since that time, extensive monitoring has allowed for continual evaluation and adjustment of the decision support model and associated water releases by the dam. Over the past 10 years, USGS, in collaboration with other groups, has been conducting biannual monitoring studies of over 70 fishes and invertebrates on various shoals along regulated and unregulated river reaches. By monitoring and comparing fish abundance, occupancy, and reproductive observations with river flow and temperature data, they are beginning to generate a clearer picture of how various flow regimes influence native biota. Fish and flow monitoring, combined with surveys (e.g., survey of anglers and boaters) and monitoring efforts related other stakeholder objectives, allows researchers and stakeholders to fine-tune the decision support model for R.L. Harris Dam, contributing to improved flow management that meets a variety of needs. Further, stakeholders have been kept apprised of monitoring findings over the 10-year monitoring period, and will use collected information to inform the formal relicensing of R.L. Harris Dam from 2017-2021.

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[19] Auburn University, Adaptive Management of R.L. Harris Dam and the Tallapoosa River: http://www.ag.auburn.edu/fish/research/research-programs-in/natural-resources/adaptive-management-of-r-l-harris-dam-and-the-tallapoosa-river/

[20] Objectives included the following: Maximize – economic development, diversity and abundance of native fauna and flora, water levels in the reservoir, reservoir recreation opportunities, boating and angling downstream from the dam, and power operation flexibility. Minimize - bank erosion downstream from the dam, total cost to the power utility, river fragmentation, and consumptive use.

Although not explicitly incorporated at this time, the decision support model has the capacity to integrate projected changes in water availability due to regional climate change. The model already captures some climate-related variables, as over the course of the 10-year monitoring period, the Tallapoosa River has experienced both drought and flood periods. Thus, the model incorporates how these various water years affect local biota.

Great Dismal Swamp National Wildlife Refuge

USGS researchers and Great Dismal Swamp National Wildlife Refuge (GDSNWR) managers in Virginia are partnering to better understand how climatic variability and different management actions interact to affect habitat resilience and restoration, ecosystem service provisioning, and carbon sequestration.[21] The GDSNWR serves as an ideal location for such collaboration, as refuge managers are under a federal mandate to restore swamp hydrology to increase habitat resilience, while USGS is acting under a federal mandate to improve carbon storage on public lands. Restoring swamp hydrology is likely to improve peat soil formation and enhance carbon storage and wildlife habitat, achieving management goals for both groups.

USGS's project will both interact with and inform management of the GDSNWR. USGS researchers and other partners are combining field data (e.g., carbon storage and flux, biomass, soil moisture, hydrological monitoring) and historic data to conduct an ecosystem services assessment. This assessment will facilitate the creation of a state and transition simulation model, which will examine how climatic variability and management decisions affect swamp vegetation types, and thus, various ecosystem services, including priority services identified by regional managers and stakeholders (i.e. carbon sequestration, wildlife viewing, nutrient cycling, flood protection, and fire mitigation). Simultaneously, GDSNWR managers are implementing adaptive management to achieve habitat restoration and enhancement goals. For example, the refuge currently operates 45 different water control structures to both slow and direct water movement on the swamp landscape to restore natural hydrologic seasonality and flow path. Monitoring data will be integrated into USGS's model, and refuge managers hope to use this model and other information from the study to inform resilient swamp management and decision-making in the future, particularly by evaluating different management tradeoffs.

Natural Resource Management and Conservation

Incorporating climate adaptation into natural resource management and conservation is key to decrease vulnerability and increase resilience in ecosystems. Examples include enhancing areas under protection, restoring critical ecosystems, and reducing non-climate stressors that may exacerbate the effects of climate change.

Enhance areas under protection

This strategy includes protecting adequate and appropriate space and improving the management of existing protected areas and refugia (Hansen and Hoffman 2010), which may

[21] USGS, The Great Dismal Swamp Project: http://www.usgs.gov/climate_landuse/lcs/great_dismal_swamp/GDS_project.asp

be at risk. Freshwater, terrestrial, and coastal ecosystems all play important roles in preserving water supply, quality, and delivery. Managers and planners may decide to create new protected areas, increase the size and number of protected areas, or create networks of protected areas in order to preserve ecosystem functions and processes. Examples from our survey include wetlands, forests, and watersheds.

Wetlands

The North Florida Wetlands Conservation Project (NFWCP) aims to protect a network of freshwater wetlands in north central Florida. NFWCP is starting to look at climate change as a factor in conserving lands with guidance from University of Florida to improve water conservation and ecosystem retention of water resources. NFWCP is looking at how to manage conservation lands for increased water retention by assessing which habitats retain more water in the system. They are also considering sea level rise when making any new conservation land investments in the coastal area.

Forests

In 2012, the USFS released a Planning Rule requiring the integration of climate change impacts, vulnerability, and adaptation into revisions of forest management plans. Three national forests are undergoing these revisions in the region, including the Nantahala and Pisgah National Forests in North Carolina, the Francis Marion National Forest in South Carolina, and the El Yunque National Forest in Puerto Rico.

The Nantahala and Pisgah National Forests feature streams and rivers as well as manmade reservoirs used for water supply, flood control, hydroelectric power, and water-based recreation. Drinking water for eleven municipalities is derived from the forests. These systems are at risk from climatic changes such as increasing wildfire, insect and plant invasions, disease outbreaks, drought, and extreme weather events. Draft management strategies include maintaining and restoring microsites most likely to be resilient to changing conditions, restoring native vegetation in riparian zones to help moderate water temperature increases and streamflows, and maintaining forest health to reduce the effects of water stress on forest stands and preserve natural water supplies.[22] The final plan is expected in 2018.

The Francis Marion National Forest's revised plan incorporates climate change considerations and promotes hydrological restoration (FMNF 2017). The 1996 Francis Marion Forest Plan focused largely on helping the forest recover from hurricane impacts, while the revised forest plan shifts management emphasis to ecological restoration of longleaf pine and isolated wetland ecosystems and using restoration to contribute to the economic and social sustainability of the region. Wetland restoration will benefit wildlife habitat, as well as help capture and hold stormwater, increasing flood protection for adjacent communities and helping recharge groundwater. In addition, restoring the natural hydrology of the forest's wetlands may help mitigate some of the salinization occurring in nearby coastal communities, many of which are experiencing saltwater intrusion into drinking water wells.

[22] Nantahala and Pisgah National Forests Plan Revision: https://www.fs.usda.gov/detail/nfsnc/home/?cid=stelprdb5397660

The El Yunque National Forest is the only tropical rain forest in the U.S. National Forest system. Located in the Sierra de Luquillo Mountains, the forest features diverse vegetation types, waterfalls, and pools that provide habitat for over 180 animal and 636 plant species. The mountains are also a major water source for the island, supplying more than 20% of the municipal water source with approximately 46 million gallons of water withdrawn per day. Since 2014, the forest has been undergoing the revision process. The revised plan emphasizes restoring and protecting ecosystems that are resilient to climate change and other stressors (EYNF 2016). Desired conditions include retaining wetlands and ponds to support cool, moist conditions for species and water supply, and prioritizing riparian zones to maintain water supply and quality. Management strategies associated with water resources in the forest include no further authorizations for consumptive water intakes and protecting surface and groundwater supplies from pollution.

Watersheds

The Mobile Bay National Estuary Program, in collaboration with the Mississippi-Alabama Sea Grant Consortium and many state, local, and private stakeholders, developed a climate-informed Comprehensive Watershed Management Plan (MBNEP 2014) to guide the restoration of Three Mile Creek, an urban stream in Mobile, Alabama. Three Mile Creek, like many watersheds in coastal Mississippi and Alabama, has water quality issues (e.g., nonpoint source pollution, sedimentation) that are exacerbated by stormwater and flood episodes, and has historically been considered a liability rather than an asset for the city. By developing and implementing a comprehensive Watershed Management Plan (WMP), city residents and the MBNEP hope to transform this degraded urban creek into a watershed that supports natural and human communities. For example, the restored watershed will enhance natural hydrology and water quality, improving fish and wildlife habitat, as well as bolstering community assets by increasing property values and serving as an ecotourism destination by developing civic and green space. As a living document, the WMP will be updated as conditions change, and a monitoring component will allow managers to evaluate the effectiveness of plan implementation efforts and change strategies and goals accordingly in the future. In addition to addressing pollution and restoration objectives, the Three Mile Creek comprehensive WMP incorporates climate change impacts. The Three Mile Creek watershed and related management goals and strategies are sensitive to climate change, particularly sea level rise, storm surge, and increasing storm/precipitation intensity, which could lead to inundation of low-income communities and wetlands, saltwater intrusion into groundwater sources, and freshwater availability shifts affecting both groundwater and habitat and species distributions. The WMP incorporates several climate change components, including: a process-based model that will assess sensitivity of water quality and availability to future climate conditions by examining feedbacks between surface water, land surface, soil and groundwater; climate change scenarios and vulnerability assessments for a variety of resources; a NatureServe Climate Change Vulnerability Index; and a VCAPS for air temperature and fecal coliform. Further, all management strategies proposed by the WMP must be informed by and/or incorporate climate change impacts.

The St. Croix East End Marine Park (STXEEMP) is a 60-mi^2 marine area surrounded by six watersheds covering 12 mi^2. Seven percent of this land area is impervious cover. In 2011, the NOAA Coral Reef Conservation Program sponsored a watershed assessment and planning process to identify land-based threats and management alternatives. The USVI Department of Planning and Natural Resources, St. Croix Environmental Association, The Nature Conservancy, and others partnered to identify key watershed concerns and recommend restoration activities. Runoff from impervious surfaces and agricultural lands, as well as wastewater discharges and illegal dumping, are major sources of concern in the area. Strategies recommended include adopting stormwater quality standards for development and redevelopment activities, supporting ongoing conservation and restoration activities across the watersheds, reducing sediment loads through road and drainage improvement projects, retrofitting existing development to manage untreated stormwater runoff, and managing pollutant loading from rural lands. The STXEEMP Watersheds Management Plan was released in 2011 to establish priority actions for the area (Horsley Witten Group 2011).

The St. Thomas East End Reserves (STEER) system is a 3.7-mi^2 area of marine reserves and wildlife sanctuaries, including Mangrove Lagoon, Benner Bay, Compass Pt. Salt Pond, Jersey Bay, Nazareth Bay, Cowpet Bay, and Great Bay. The watershed that drains into these waters encompasses 6.2 mi^2 of upland habitats. In 2011, the NOAA Coral Reef Conservation Program sponsored a watershed assessment and planning process to identify land-based threats to STEER. The USVI Department of Planning and Natural Resources and The Nature Conservancy created the STEER Watershed Management Plan in 2013 to establish priority actions for the area (Horsley Witten Group 2013). Strategies include reducing nutrient and pathogen loading through improvements to wastewater infrastructure, improving management of stormwater runoff from existing and future development, minimizing pollution in the drainage system, and protecting and restoring wetland habitats. Twenty percent of the watershed is impervious cover, allowing large amounts of surface runoff into receiving streams and bays. Actions related to reducing the effects of runoff include minimizing the removal of native vegetation, reducing impervious surfaces, capturing runoff in cisterns and detention ponds, and reusing runoff wherever possible. However, there is a current lack in stormwater improvement standards and policies in the USVI. The Watershed Management Plan provides an initial list of prioritized restoration activities in each of the sub-watersheds – Bovoni, Turpentine Run, Nadir Gut, Frydenhoj/Compass Pt., and Nazareth, Cowpet, and Great Bay – based on potential costs, property ownership, and stakeholder priorities.

Restore critical ecosystems

Restoration is a key activity in natural resource management and conservation. Many restoration activities will, in general, enhance the resilience of ecosystems. Freshwater, terrestrial, and coastal habitats help to protect and preserve regional water resources. In addition, many of these systems act as natural buffers to flooding, storm surge, and sea level rise. Many habitats have been degraded or destroyed by both human activities and natural processes; restoring these systems can help recover critical ecosystem functions and services.

Examples from our survey include habitats in southwest Florida, coastal Louisiana, southern Chesapeake Bay, and the USVI.

In partnership with the South Florida Water Management District and USACE, the Conservancy of Southwest Florida is undertaking the Picayune Strand Restoration Project to restore historic water flows, recharge aquifers, provide flood protection, and protect water supply across 55,000 acres of native Florida wetland and upland habitat. This is the first Comprehensive Everglades Restoration Plan project to begin construction. This land was drained back in the mid-1960s by a network of 40 miles of canals and 227 miles of road to provide land for future development, diverting water into the Gulf of Mexico and damaging coastal wetlands. Although many efforts were made to drain these wetlands, lands were still inundated during the wet season, making them unbuildable. In the mid-1980s, the State of Florida began buying back the lands from private landowners to restore the area and rebuild a functioning wetland. To date, seven miles of canals have been filled, 65 miles of roads removed, and three pump stations (Merritt, Faka Union, and Miller Canal) constructed to maintain current flood protection while directing fresh water downstream. This project will benefit the Florida Panther National Wildlife Refuge, Fakahatchee Strand State Preserve, Rookery Bay Reserve, and the Ten Thousand Islands Refuge.

The freshwater wetlands of Jean Lafitte National Historic Park and Preserve are vulnerable to a variety of climate-driven hydrological changes, including sea level rise, increasing storm surge, frequency and intensity, and increasing precipitation intensity. Regional land subsidence, exacerbated by reduced sediment delivery to coastal wetland systems as a result of significant upstream levee systems on the Mississippi River, contributes to this region having one of the fastest rates of relative sea level rise in North America. The landscape is also fragmented by extensive canal systems, which allow seawater to travel significantly inland. These canals, combined with sea level rise and increasing storm surge, are causing increased salinization in park freshwater wetlands, leading to altered vegetation communities and inhibited disturbance recovery. The park is undertaking a variety of efforts to minimize these impacts, including canal backfilling and encouraging regional river and sediment management. By reducing the breadth and depth of canals through canal backfilling, the park hopes to restore freshwater wetland function, enhance wetland area, and enhance habitat resiliency to climate impacts. The park has completed several miles of canal backfill projects since the early 2000s and has secured permitting to backfill an additional 16.5 miles, pending financial support. This on-the-ground management is also paired with policy and planning work aimed at mitigating sea level rise through river and sediment management to enhance natural land building processes in regional coastal wetlands.

The Elizabeth River Project is a non-profit organization attempting to restore baseline conditions of the Elizabeth River in Virginia to make it “swimmable and fishable by 2020.” In collaboration with stakeholders – including industrial users, local communities, reservoir managers, and state and local governments – the Elizabeth River Project helped write the Elizabeth River Action Plan and subsequent five year updates that address emerging issues within the watershed. The River Action Plan is a living document that focuses on river restoration, education and community outreach; it includes sub-watershed goals and actionable steps and timelines to achieve these goals, which facilitate plan implementation. Sea level rise, and its impacts on the longevity and success of different plan components, is a new addition to the most recent River Action plan and is incorporated into restoration projects. For example, wetland restoration projects along the Elizabeth River are designed to allow for wetland retreat in response to rising ocean levels, and the vegetation planted in restoration sites is designed to allow for natural succession to more hydrophytic species, which can withstand more frequent inundation. The Elizabeth River Project has helped design and implement over 100 river buffer and wetland projects over the past 15 years, and is also involved in long-term monitoring of these projects to evaluate their impact on water quality. Restored areas are also used as living classrooms for local schools, and students learn about the economic and environmental importance of healthy watersheds. In addition to its restoration and education efforts, the Elizabeth River Project also conducts pollution reduction outreach to local industries and governments, and partners with landowners to improve riparian habitat and reduce nutrient delivery to the river.[23]

The Watershed Stabilization Project was created to target sediment control and cleanup in Coral Bay and Fish Bay, St. John, and East End Bay, St. Croix (Reed 2012). The Virgin Islands Resource Conservation and Development Council, Coral Bay Community Council, and partners received $2.7 million in American Recovery and Reinvestment Act funds in 2009 to restore natural drainage functions and decrease runoff in six sub-watersheds. Upland development, steep slopes, and a high number of unpaved roads cause excessive sedimentation rates in the region. The project successfully reduced sediment loads at several sites, the majority of which were targeted at reducing sediment at its source. For example, construction activities at 70 sites included installing swales, culverts, and roadside drainages and paving roads to reduce sediment inputs, while 15 sites targeted sediment cleanup through bioretention ponds, sediment detention basins, check dams, step pools, and rain gardens. Through this project, 59 jobs were created, 0.22 miles of riparian habitat restored, and 130 tons per year of sediment loads reduced. Lessons learned from the implementation of these actions at different sites are documented and have been used to define best management practices for stormwater control.

Reduce non-climate stressors likely to interact with climate change

Numerous non-climate stressors already affect regional water resources, which may make them more vulnerable to climate change. The cumulative effects of stressors, such as water withdrawals, pollution, and non-native or invasive species, reduce the overall resilience of natural systems. Examples of reducing non-climate stressors likely to interact with climate change include minimizing runoff through climate-smart landscaping (i.e. xeriscaping), reducing pollution, and limiting development in vulnerable areas (i.e. watersheds, coastlines).

[23] Elizabeth River Project: http://www.elizabethriver.org

Xeriscaping

The Urban Forest (UF) program of Chattanooga, Tennessee, is using IPCC projections to select and plant resilient tree species that will maximize stormwater retention and minimize overland flow and stormwater costs for the city. Like all cities in the United States, Chattanooga must meet the Municipal Sanitary Storm Sewer Systems (MS4) permitting regulations, which require cities to "catch" the first inch of rainfall. For Chattanooga, planting more trees and increasing canopy cover has been a cost-effective way to meet MS4 criteria, and is now an integral component of the city's Runoff Reduction Standards. By capturing and retaining stormwater, urban forests reduce runoff, stormwater treatment costs, and pollutant delivery to local waterways. To maintain these important ecosystem services both now and in the future, the Chattanooga UF program is planting drought- and heat-tolerant species that will withstand the drier and hotter conditions projected by the IPCC. In addition, the UF program selects for large canopied and large leaf tree varieties to maximize water retention. Chattanooga has achieved 51.4% canopy cover for the entire city, and is now focusing on achieving 15% canopy cover in the downtown district to further improve stormwater retention, increase shading, and bolster local species diversity.

The Mountain Valleys Resource Conservation and Development Center (MVRCDC) is one of many groups working to improve water quality in the Ivy River watershed. The Ivy River serves as a drinking source for two different municipalities, but is listed on the EPA's 303d list for high levels of turbidity and fecal coliform. MVRCDC is currently focused on bringing various stakeholders together to form a regional approach to watershed management and to implement components of the Ivy River Source Protection Plan, which was developed in late 2012 (MVRCDC and MCSWCD 2013). Water quality enhancement activities being implemented in the watershed vary from communicating and improving use of agricultural BMPs, to septic repair projects, to school engagement and stormwater garden installation. The Source Water Protection Plan, as well as MVRCDC staff and regional collaborators, recognize that increasing stormwater runoff and erosion related to increasing storm frequency and severity could undermine water quality projects. For example, large rain events have caused slope collapse in several stream restoration sites, requiring further monetary investment for enhanced stabilization efforts. In current and future planning efforts, MVRCDC and partners are keeping trends in runoff and erosion in mind, and trying to design projects to be robust as possible.

Reducing pollution

The Tennessee Clean Water Network (TCWN) specializes in water quality policy and litigation. Key priorities include increasing industry compliance and state implementation and enforcement of the Clean Water Act and the Tennessee Water Quality Control Act. The TCWN runs two separate programs to help achieve these goals. The Wetland Mitigation Inspection Program evaluates the success of wetland mitigation projects. Reviews of past projects identified that very few, if any, wetland mitigation projects in Tennessee were completed or maintained according to permit requirements. The TCWN brought this issue to the state, resulting in increased protection and management of over 130 wetland acres over the course of 3 years. In addition, the state has recently developed new permit revision and follow-up protocols to improve wetland mitigation monitoring. The TCWN also runs a Pollution

Prevention Program, which reviews state-issued discharge permits and monitors real-time discharge activity from a variety of sources, including industrial plants, coal mining operations, construction sites, and sewage plants. Through this program, TCWN attempts to proactively work with both the state and polluting agencies to improve discharge permit compliance; if compliance is not met, TCWN moves to litigation in order to get results. The Pollution Prevention Program is also attempting to help the state improve its environmental regulations. For example, TCWN is attempting to change the board that oversees state water issues and update regulations and policies so that discharge problems can be addressed earlier. Despite the fact that sewage overflows and bypass treatments as a result of large rainfall events (which are projected to increase in frequency and severity) are one of the primary violations that TCWN uses as grounds to sue negligent or unresponsive agencies, TCWN has not seen any state, local, or private management agencies adjusting protocols to deal with larger or flashier stormwater events. The TCWN hopes to incorporate this line of thought in future efforts and collaborative work with state, local, and private agencies.[24]

The Gulf Restoration Network is a community advocacy and policy group that aims to make the Gulf Coast resilient to climate change impacts and ensure that industry and government responsibly use current water resources. For example, the Natural Defenses and Wetlands Initiative helps Gulf Coast communities hold oil and gas companies accountable for coastal wetland degradation and subsequent increased community vulnerability to flooding and other climate change impacts. Fines and payouts from community lawsuits are used for coastal restoration activities, and help increase community resiliency to sea level rise and flooding. In addition, the Gulf Restoration Network encourages local communities and state representatives to develop and implement adaptation plans to better manage wetland loss and sea level rise. For example, the Gulf Restoration Network published a Wetlands Protection Manual in 2001 to help communities protect local wetland resources and associated ecosystem services they provide. The Gulf Restoration Network works in five Gulf States, including Louisiana, Alabama, Mississippi, Florida, and Texas, as well as collaboratively with many other regional organizations.[25]

Limiting development in vulnerable systems

The Conservation Trust for North Carolina is coordinating the Upper Neuse Clean Water Initiative (UNCWI),[26] a collaborative effort between regional land trusts, other non-profit entities, and several local municipalities and counties to maintain drinking water supplies and quality in the Upper Neuse River Basin and Swift Creek Watershed. In 2005, the UNCWI developed a conservation plan to identify land areas with highest conservation priority in relation to water resources (i.e. lands that, if converted for agriculture or development, could seriously degrade water quality). Over the 10 years since plan development, UNCWI partners have protected 85 properties through purchases or conservation easements, protecting a total of 7230 acres and 66 stream river miles. These protected acreages help maintain water quality and quantity by slowing and filtering precipitation and runoff, and will continue to play a critical

[24] Tennessee Clean Water Network: http://www.tcwn.org
[25] Gulf Restoration Network: https://healthygulf.org
[26] Upper Neuse Clean Water Initiative: http://www.ctnc.org/assist/upper-neuse-clean-water-initiative

role in drinking water provisioning for municipalities in light of projected population growth and climate variability. UNCWI partners plan to update the Conservation Plan in 2015, and the revised plan will feature updated land cover data and new prioritization criteria for protected land selection. These criteria will be generated from stakeholder input, and reflect what land factors are most critical to consider to maintain water quality (e.g., cover type, amount of green infrastructure present, slope).

Infrastructure, Planning, and Development

This category deals with climate-related threats to water resources and communities from increased temperatures, storm frequency and intensity, changes in precipitation, and increased flooding and erosion. Planners need to identify and assess vulnerabilities and develop responses to protect infrastructure and public health and safety, all while limiting environmental damage. Strategies within this category include improving existing or designing new infrastructure to withstand the effects of climate change, incorporating climate change into community and land use planning, creating or modifying development measures (e.g., removing shoreline hardening, encouraging low impact development), and developing disaster preparedness plans and policies.

Make infrastructure resistant or resilient to climate change

Incorporating climate change into the operations, retrofitting, or development of existing and new infrastructure and plans dealing with water supply, stormwater, and wastewater systems may help limit the effects of climate change on water resources. Changes in temperature and the intensity of storms and precipitation patterns will cause lake level changes, erosion, and flooding that will in turn increase the risk of infrastructure damage or malfunctions, decreased water quality, and fluctuating water supply as the magnitude, frequency, and duration of water flows changes. Climate change needs to be integrated into both water resources infrastructure and management. Water resources infrastructure serves to convey, store, and protect water. Conveyance (e.g., channels, pipes), storage (e.g., reservoirs), and protective (e.g., levees, dams) measures all serve to manage water at specified levels; climate-driven changes will create highly variable conditions that will complicate the business-as-usual (or stationarity-driven [Milly et al. 2008]) approach commonly employed by water management authorities. This strategy includes recognizing the linkages between land and water use, water quantity and quality, information exchange and decision making, and demand and supply (Kundzewicz et al. 2007; Brekke et al. 2009).

Create new or retrofit water resources infrastructure

In the City of Newport News, the Waterworks utility is in the process of rebuilding the Walker Dam, a saltwater intrusion prevention dam on the Chickahominy River. As a hedge against increased sea levels and larger storm surges and tidal fluctuations, the dam now includes designs for flash fjords, structures that are temporarily raised to increase dam height and prevent saltwater intrusion into the upstream intake site. Waterworks is also rebuilding and refurbishing its other dam structures; though much of this work was mandated due to aged dams and elevated flood risk due to changes in population size and location, Waterworks has capitalized on these mandated updates by choosing to incorporate climate change into refurbishment designs. For example, its refurbished dams are now designed to better withstand 100-year storm events and storms of greater intensity and duration.

The City of Miami Beach is updating its stormwater management plan[27] to improve the city's stormwater system and water quality. The city is located on a low-lying barrier island and is vulnerable to flooding and saltwater intrusion from storm surge and sea level rise. During high tides and heavy rainfall, Biscayne Bay water backflows into the current stormwater system, flooding roads and neighborhoods. The new master plan incorporates projected sea level rise in order to modernize existing systems for flood and water quality control and meet increasing performance and regulatory demands. The city tested stormwater flood control with pump stations during heavy rainfall events in a few areas; areas subjected to pumping were completely dry while non-pumped areas experienced significant flooding. The city is currently undertaking a feasibility study to ensure pumping stations are placed throughout the priority areas and looking at other possible alternatives such as deep well injections for water discharge.

Miami-Dade County is concerned about the impacts of projected sea level rise and increased storm surge on water resources and infrastructure. Saltwater intrusion into the Biscayne Aquifer is a potential issue due to the hydrological connection and dependence of the county on groundwater as its primary source of drinking water. The county is in the process of upgrading its water and sewer systems, covering 13,000 miles of pipes and six main treatment plants. Improvements include removal of ocean outfalls for treated wastewater to reduce nutrient inputs, and retrofits to wastewater collection and pump stations.

The USACE and Tetra Tech partnered to design the innovative Lake Borgne Surge Barrier that reduces 100-year flood risk in New Orleans. The entire storm surge barrier is the largest civil engineering project in USACE history. The constructed 10,000-foot long, 26-foot high concrete wall stretches across the Mississippi Gulf River Outlet, and contains three vessel passage gates. The sector gate at the Gulf Intracoastal Waterway, conceived and designed by Tetra Tech, is buoyant, and can rise in response to increasing water levels. The design and integration of this buoyant gate extends the life of the project beyond its required 50-year lifespan, as the gate is adaptable to different water level conditions. Overall, the construction of this storm surge barrier reduced the need to replace and elevate 30 miles of existing floodwalls and levees, and moved the focal point of the flood protection system away from New Orleans' city center. This project occurred at the same time as a separate pumping system upgrade, but together, both projects will help reduce saltwater and freshwater flooding in the city.

Assess integrity of water resources infrastructure

The Apalachicola-Chattahoochee-Flint River Basin is a large watershed spanning western Georgia, southeastern Alabama, and the central Florida Panhandle before draining into the Gulf

[27] City of Miami-Beach Public Works Stormwater Utility Division: http://miamibeachfl.gov/publicworks/scroll.aspx?id=27280

of Mexico. Several extreme weather events have recently affected communities in North Georgia, including severe droughts in 2007-2008 and 2011-2012, and floods in September 2009 and the winter of 2009-2010. Drought and flooding events are projected to intensify under climate change. During and after these events, water utilities were faced with continuing to provide reliable supply and service while complying with environmental regulations. Lessons learned during these events have allows water utility managers to identify climate-resilient practices. For example, during the droughts, Gwinnett County imposed water restrictions and adopted a tiered billing structure wherein the price of water rose with use, which reduced consumption by 20%. As a result, water utilities experienced reduced revenue, which caused them to renegotiate electrical rates and close older facilities. During the 2009 flooding event, the priority was to restore potable water and wastewater services to the region as quickly as possible. Atlanta's wastewater utility had an emergency response plan in place, which defined priority areas and operations that could be supported by portable pumps and generators. To address future extreme events and improve natural recharge of the basin, local communities are promoting green infrastructure, water conservation, and xeriscaping. Additional actions that may be explored to provide a robust water supply in light of climate change include creating new reservoirs, expanding aquifer recharge systems, restoring natural hydrology, and implementing inter-basin transfers.

Increase capacity for treatment of degraded water (e.g., injection wells, desalination)
The City of Punta Gorda received funding in 2014 to design plans for a Reverse Osmosis Water Treatment Plant and Brackish Groundwater Supply Project (FLDEP 2014). The goal is to develop a sustainable water supply for the region. Punta Gorda relies on the Shell Creek reservoir, which is susceptible to drought conditions and variable water quality, and does not currently the state and national requirements of Total Dissolved Solids year round. To address these issues, the city has recommended a multi-jurisdictional water supply system comprised of groundwater, surface water, and off-stream reservoirs to take full advantage of changes in climate. Groundwater will have to be treated by reverse osmosis since it is partially saline. This will provide a reliable source of water that is less influenced by climatic conditions and provide backup water supply if Shell Creek cannot meet future demands.

Tampa Bay Water is a drinking water utility servicing over two million residents in Hillsborough County, Pasco County, Pinellas County, New Port Richey, St. Petersburg, and Tampa. Historically, the region relied exclusively on groundwater pumping for its water supply; however, saltwater intrusion and overpumping in the 1980s triggered a shift to 60% surface water supply from local rivers and the bay itself. However, the 1999-2001 drought required the utility to again pump groundwater to match consumer demand; the extent of this extraction had major impacts on the surrounding natural environment. The region is experiencing increasingly higher seasonal climatic variability, which may drive even more frequent droughts; at the same time, water demand will increase as the regional population grows. The utility constructed a $158-million desalination plant to protect groundwater sources from saltwater intrusion, as well as a $140-million, 15-billion-gallon reservoir that stores water from the Alafia River, Hillsborough River, and Tampa Bypass Canal. These measures provide back up water supply during periods of drought, including during the recent April 2017 drought.

Community planning (developing climate-informed communities)

Local planning and engagement are key to adaptation implementation. Examples from our survey include cities and counties in Alabama, Mississippi, Georgia, North Carolina, and South Carolina. The Gulf of Mexico Alliance and the Mississippi-Alabama Sea Grant Consortium worked with the City of Orange Beach, Alabama to conduct an in-depth vulnerability assessment using VCAPS and the Community Resilience Index (CRI), a tool that examines community preparedness for storms and storm recovery (Sempier et al. 2010). Residents identified heavy rainfall and severe coastal storms as the key sources of flood risk for their community. Using VCAPS and CRI, the city explored: (1) how changes in frequency and intensity of these events could increase the city's vulnerability (e.g., drainage ditches can be eroded or blocked and cause localized flooding following downpours, salt water from storm surges can infiltrate sanitary sewer system and damage wastewater treatment facility); (2) what adaptive management actions could be taken to reduce those vulnerabilities; and (3) who would theoretically be responsible for those adaptation actions (e.g., Public Works department could create water-tight manhole covers and shut down pumps for sanitary sewer post-storm until stormwater has drained) (Webler, Tuler, and Oriel 2012). Orange Beach officials were able to integrate adaptation options into their city emergency plan, improving the city's resilience to extreme weather events.

Urban forestry represents a significant opportunity to enhance community resilience to climate change as tree canopies mitigate urban heat islands, buffer storm winds, and reduce stormwater pollution by intercepting and slowing precipitation. Mississippi State University scientists are engaging with four communities in Mississippi and Alabama to better understand current perceptions and use of urban forestry, increase community understanding of urban forestry, enhance baseline urban forestry data available for making informed decisions, and improve local resilience through urban forest management.[28] Community participation serves as the backbone of this project. To better understand how communities currently view and utilize urban forestry, as well as to enhance communication about urban forestry benefits, project staff are engaging with community members through three avenues: individual interviews, public workshops, and a mail survey to the general public. Project staff are also coordinating with municipalities to conduct a volunteer-driven tree inventory, as baseline data will be a critical component of future urban forestry planning. Volunteers were trained to gather tree information in their areas using a combination of the free phone applications i-Tree and TreeMetrics (developed by project staff). Volunteers are currently gathering metrics including tree geographic coordinates, height, diameter, canopy characteristics, building proximity, and ground surface characteristics. This baseline data, along with understanding how these communities currently view and utilize urban forestry, will hopefully be used in future efforts to create Urban Forestry Plans to enhance the resilience of these pilot communities. Utilizing urban forestry for stormwater mitigation will be a component of these plans.

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[28] Mississippi-Alabama Sea Grant Consortium, Risk reduction through coastal urban forest management outreach: http://masgc.org/projects/details/risk-reduction-through-coastal-urban-forest-management-outreach

The Carolinas Coastal Climate Outreach Initiative (CCCOI) was developed in 2006 to help coastal communities to understand and plan for climate impacts along the coast as a multi-disciplinary research and outreach team. Together the South Carolina Sea Grant Consortium, North Carolina Sea Grant College Program, and the Carolinas Integrated Sciences and Assessment (CISA) are working to help communities become more resilient, assess vulnerability, and develop adaptation strategies. The program provides climate science and regional downscaled climate and hydrological models to help communities understand and better plan for anticipated climate impacts, including drought, changes in precipitation, severe storms, sea level rise, and saltwater intrusion. The CCCOI has been using VCAPS to help communities adopt a risk-based approach that integrates local knowledge. The CCCOI has supported planning for changes in stormwater management in McClellanville, South Carolina (CISA and SERI 2011) and Plymouth, North Carolina (Putnam et al. 2012); planning for flooding from sea level rise in Sullivan's Island, South Carolina (CISA and SERI 2010); and assessing infrastructure vulnerability in Charleston, South Carolina. Additional community resilience planning projects are being held in Beaufort County, South Carolina; St. Marys, Georgia; and Hyde County, North Carolina.[29]

Chatham County, Georgia is vulnerable to sea level rise, flooding, and erosion. Increasing the ability of the county to adequately prepare for and recover from the impacts of climate change are important goals of the Chatham County – Savannah Metropolitan Planning Commission. These goals have expanded into ensuring that all areas of the county are preparing for climate change, including public works, fire departments, hospitals, board of educators, and county engineers. The county updated its comprehensive plan to examine how to integrate climate-informed principles into growth and development decisions over the next 20 years. Chatham County is now updating its zoning ordinances and subdivision codes to prioritize low impact development and green infrastructure as part of resilience planning. In addition, all the municipalities in Chatham County have updated their stormwater policies and adopted the Coastal Stormwater Supplement of Georgia's Stormwater Management Manual. The supplement addresses ways to address flood vulnerabilities in development efforts to protect and maintain the integrity of local aquatic resources. It includes design recommendations to help protect local aquatic resources, reduce flooding through post-construction stormwater management and site planning design, and improve water quality through green infrastructure.

Create or modify development measures

Modifications to development practices can help support the protection of water supply, quality, and delivery. This includes using natural and nature-based features to stabilize banks and trap sediments from runoff, and green infrastructure (CCAP 2011) and low impact development practices, including permeable surfaces, swales, water retention ponds, green roofs, urban forestry, green alleys and streets, rain barrels, and rain gardens.

Improve flood protection measures (e.g., "soft" and "hard" measures)

The Louisiana coast is vulnerable to flooding, erosion, and saltwater intrusion from sea level rise and extreme weather events. Wetland losses from Hurricanes Katrina and Rita – estimated

[29] Places that have used VCAPS: http://www.vcapsforplanning.org/places.html

to be approximately 100 mi^2 – motivated the Lake Pontchartrain Basin Foundation (LPBF) to create the Multiple Lines of Defense Strategy,[30] a plan to integrate coastal habitat protection and restoration and engineered flood protection measures. Core priorities of the strategy are to strategically implement both natural and built features that help buffer the coast from flooding and erosion. The eleven "Lines of Defense" identified include features such as the Gulf of Mexico shelf, barrier islands (i.e. Chandeleur Islands, Grand Isle), sounds (i.e. Breton Sound, Chandeleur Sound), marsh landbridges (i.e. Biloxi Marsh, New Orleans East, Maurepas), natural ridges (i.e. Bayou la Loutre, Bayou Lafourche), coastal highways (i.e. Highway 90, Highway 82), flood gates (i.e. Bayou Bienvenue, Bayou Dupre), levees (i.e. St. Bernard, Jefferson and Orleans Parish), pumping stations, building elevations, and evacuation routes (Lopez 2006). LPBF also identified target wetland habitat types for prioritization of restoration activities: salt marsh, brackish marsh, intermediate marsh, and freshwater marsh. Mapping and comparing the Lines of Defense and target habitats helps managers and planners make strategic decisions regarding coastal restoration and development. LPBF used the Multiple Lines of Defense Strategy to evaluate over 100 proposals and selected restoration projects that provide both habitat restoration and flood protection benefits for Lake Pontchartrain and the Greater New Orleans area. These projects include using a combination of rock armoring, beach nourishment, oyster reef creation, and marsh revegetation at 10 sites: Lake Borgne Landbridge, Bayou la Loutre Ridge, Chandeleur Barrier Islands, Jefferson Parish, Violet, Biloxi Marsh Landbridge (at two sites), Breton Landbridge, New Orleans East Landbridge, and Maurepas Landbridge.

Protecting estuaries and shorelines from sea level rise and storm surge helps protect natural environments and water systems from fluctuations in salinity and coastal erosion. Using oyster reefs as a natural buffer along the undeveloped coastline of the Big Bend of Florida will protect freshwater resources, particularly the Suwannee River. Oyster reefs in the region have been disappearing since the 1970s and 1980s due to decreased inputs of fresh water in the estuary in the Gulf of Mexico. Increased water demands in the Suwannee for municipal and agriculture uses is altering freshwater flows into the estuary, killing many of the region's oyster reefs, which historically served as a makeshift dam to hold fresh water from the Suwannee River up against the salt marsh. These oyster reefs provide critical structure to hold freshwater in the estuary, protect the shoreline, maintain water quality, and serve as habitat for many species. A restoration project[31] is underway to see if oyster reefs can be helped to retain more freshwater in the estuary. Researchers are looking at different structures to serve as oyster anchor sites, which would provide habitat for oysters to recolonize once conditions are favorable. The goal is to restore approximately 32 acres of oyster reef between 2017 and 2025 in partnership between the University of Florida, Florida Fish and Wildlife Conservation Commission, and the National Fish and Wildlife Foundation.

The Fairview Park and Stream Restoration Project in Montgomery, Alabama, intends to create new city green space while simultaneously enhancing water quality and helping the city better manage stormwater. The park (formerly known as Genetta Park), a four-acre urban space, has a

[30] Multiple Lines of Defense Strategy: http://saveourlake.org/lpbf-programs/coastal/multiple-lines-of-defense-strategy
[31] University of Florida Wildlife Ecology and Conservation, Recovery and Resilience of Oyster Reefs in the Big Bend of Florida: http://www.wec.ufl.edu/oysterproject/

rough history. During the 1970s, the urban stream was confined to an extensive culvert system, prohibiting natural ground infiltration. This creek acts as major drainage source for a 4.4 square mile urban sub-watershed, but in the absence of normal stream and wetland function, the creek accumulated and has been impaired by a variety of urban pollutants, including human and animal waste. Further, the site was designated as a brownfield, polluted by petroleum, hydraulic fluids, and asbestos tiles from past industrial activity. However, through careful planning and major restoration work, the unsightly area once known as the “Genetta Ditch” is slated to transform into an environmental and economic community asset. The Genetta Park and Stream Restoration Master Plan was completed in 2011, and construction has been ongoing since then. Phase 1 was completed in 2013, and involved constructing a wetland and restoring the stream. Water quality sampling, which began in 2012, has confirmed that the constructed wetland and restored stream have already begun improving water quality by reducing sediment loads, nutrient levels, suspended solids, and fecal waste through natural filtration processes. In addition, the wetland reduces flood risk by slowing stormwater and allowing for natural infiltration. Phase 2 of the project is now underway, and involves developing the surrounding park. A portion of the park will be designated for recreational use, while another portion will be developed into a Stormwater Plaza, featuring green infrastructure features such as bioswales, rain gardens, pervious pavement and cisterns. These features will not only help slow and filter stormwater, but will also help city residents appreciate and celebrate stormwater and natural ecosystem services. Once completed, designers hope that Fairview Park will draw more tourism to the culturally important downtown district and/or inspire development of a citywide greenway that would restore additional stream acreage.[32]

Merritt Island Wildlife Refuge is a 140,000-acre refuge along the Atlantic Coast of Florida that provides habitat for over 500 species, more than any other refuge in the national system. NASA originally purchased these lands in the late 1950s to provide a buffer area for rocket launches. The area was mostly uninhabited due to an extensive salt marsh, resulting in limited access and large amounts of mosquitos. Because development pressure increased in the 1950s, mosquito control became a more prevalent issue and developers dredging the salt marsh to create mosquito control impoundments (Rey and Connelly 2015). The mosquito impoundments were constructed by building levees around the marshes, capturing freshwater and eliminating mosquito breeding grounds. The impoundments helped decrease the amount of mosquitos but also caused degraded water quality and soil chemistry in the impounded wetlands. These impoundments have had a huge impact on the salt marsh and surrounding wetlands, leading to vegetation composition and species shifts. Others have proven valuable for wading migratory seabirds. Managers are now handling some mosquito impoundments differently; for example, trying to manage and restore impoundment areas to healthy marsh conditions so wetlands can buffer sea level rise, maintain connections to the Indian River Lagoon via water control structures, and capture as much fresh water as possible while maintaining salt marsh conditions and still providing habitat for migratory birds. This is an ongoing project to help maintain and restore wetlands and salt marshes, improve water quality, provide flood protection, provide habitat for threatened and endangered species.

[32] Fairview Environmental Park: http://www.2dstudiollc.com/projects/genetta-park-stream-restoration

Implement green infrastructure (e.g., rain gardens, low impact development, swales)
The Louisville Metropolitan Sewer District (MSD) is engaging in a variety of green infrastructure efforts to better manage stormwater, improve water quality, and reduce flooding in Louisville, Kentucky, and the surrounding county. The MSD's Green Infrastructure Program began when green infrastructure projects were integrated into an Overflow Abatement Plan being used to minimize combined sewer overflows. In demonstration projects implemented under this plan, green infrastructure was able to capture and store enough stormwater volume to completely eliminate the need for a stormwater/combined sewer basin. The success of the demonstration projects facilitated the creation of the MSD's Green Infrastructure Incentive Program, which provided funding for private property owners to install green infrastructure on their land. The goal of the incentive program was to reduce the amount of stormwater in each basin, thereby reducing the size of the necessary hard infrastructure capture basins which were being re-evaluated and upgraded as a part of the abatement plan. The program was highly successful and competitive, and the MSD is now transitioning its focus and funding to only a few watersheds with the highest overflow risks. Lessons learned through this program and in the original demonstration projects were distilled and compiled in to a Green Infrastructure Manual, which has undergone updates and revisions to reflect changes in MSD rules and regulations. For example, the manual has been revised to reflect and provide guidance on meeting the MS4 Stormwater Permit, which requires new and re-development projects to capture and treat the first 6/10 of an inch of rainfall with green infrastructure. Louisville MSD is also developing a new Fee in Lieu program for land parcels and development projects where green infrastructure is not feasible. Qualification for this program will be based on property infiltration capacity, presence of sinkholes or karsts, or other factors that could limit green infrastructure effectiveness or feasibility. Qualified property owners will pay a fee that goes to a general fund, which will be used to implement a water quality or green infrastructure project somewhere else within the same watershed, ensuring project benefits stay in the same area. In future revisions of the Green Infrastructure Design Manual, Louisville MSD hopes to examine how climate trends may be exacerbating or changing flood frequencies. In the interim, the MSD is engaged in some other projects through its overflow abatement plan to minimize flood risk, including buyouts of flood-prone buildings and upgrading floodwater storage basins to accommodate higher flows and then gradually release water as water levels recede.

After severe flooding in 2009 that caused $21 million in damages to 92 campus buildings, the University of Louisville partnered with the Louisville MSD to implement a variety of green infrastructure projects to help reduce stormwater delivery to the city's combined sewer system. Given that climate change may enhance the frequency and intensity of storm events, these projects will help minimize the risk of sewer overflows during high rainfall periods. With funding from the MSD, the university has installed a variety of green infrastructure projects since 2010, including underground filtration systems, green roofs, permeable pavers, rain barrels and stormwater collection cisterns, and has also actively been disconnecting downspouts and parking lots/driveways from the sewer system. The system currently diverts about 75 million gallons of stormwater per year, and helped minimize flooding during a recent severe storm in 2012. The university also has stormwater adaptation principles built into its Climate Action Plan, which was published in 2010. For example, the campus master planning chapter suggests minimizing unnecessary hardscape and planting native, deep-rooted tree species to enhance carbon sequestration and help manage stormwater. Similarly, the transportation chapter promotes student use of alternative transportation methods; in the absence of using these alternative transportation options, an increasing student population may drive increased demand for parking structures, which often increase stormwater runoff. The Climate Action Plan includes 175 recommendations for reducing university greenhouse gas emissions, and the university has reduced its emissions 27% since the plan was published.

The Cahaba River Society (CRS) works to restore and protect the Cahaba River Watershed in central Alabama. The watershed is host to rich biological diversity and a water supply source for surrounding urban and rural towns, forests, and farms. Some of the biggest challenges to the watershed's water supply and quality come from stormwater runoff from impervious surfaces and increased sedimentation from upland development. In a changing climate, Alabama is projected to experience more enduring droughts and greater deluges of rain. The river itself is changing its size to accommodate existing amounts of sediment input. Reducing the impact of sedimentation is challenged by the lack of control given to local city and county authorities over construction practices. CRS emphasizes bluer green building and low impact development (LID) approaches as standard practice in the watershed through education and outreach. Bluer green building includes promoting development and redevelopment that helps to conserve watersheds, water quality, and water supply. The core objective of this effort is to build the capacity of local governments to reduce the impact of construction-related sedimentation by demonstrating the value of LID in terms of economic, social, and environmental benefits. Part of this effort includes direct presentations and outreach to city councils and commissions, as well as developers, engineers, and architects in the region who make decisions related to growth. CRS has begun to be consulted on various LID projects in the watershed and has created an LID Toolbox on its website to provide access to critical resources on water-smart construction efforts.

The Ellerbe Creek Watershed Association (ECWA) is trying to restore and protect the hydrology of the fairly urban Ellerbe Creek Watershed of North Carolina through green infrastructure stormwater management and land protection. Green infrastructure efforts began with participation in the regional Green Infrastructure Partnership, which was jumpstarted by an EPA Urban Waters Grant. The Partnership undertook a pilot project in an urban water catchment to demonstrate and collect data on various stormwater best management practices and to highlight how reducing stormwater volume can benefit Ellerbe Creek's water quality and hydrology. ECWA is using results from the study to build advocacy and adoption of green infrastructure and other best management practices throughout the watershed, including in residential areas and as a part of city regulations. ECWA also recently undertook a priority lands analysis to prioritize land parcels within the watershed for protection. This analysis included community input on key watershed values and incorporated water quality protection elements to compare various land parcels (e.g., healthy forest extent, impervious cover, soil types). ECWA hopes to develop a living model that reflects on-going changes in land ownership within the watershed to provide continuous land parcel protection guidance to maintain watershed protection in the future.

In 2015, the City of Hot Springs, Arkansas, launched a green infrastructure planning project (GIC 2016). An advisory stakeholder committee of staff from city agencies, the Chamber of Commerce, and Visit Hot Springs was created to identify, evaluate, and prioritize the city's natural green infrastructure and strategies to protect these areas. Using satellite imagery and other data, the city mapped the extent of local natural resources such as tree canopy, wetlands, springs, rivers, trails, and parks, as well as potential flood risk zones and areas susceptible to water quality concerns. Current tree canopy covers approximately 57% of the city but is distributed unevenly. The city estimates that this canopy cover provides 1.2-1.5 million gallons of stormwater interception per year. The committee collaborated on several strategies to protect, restore, and expand the city's green infrastructure under four overarching goals: (1) connect the landscape to support wildlife and people, (2) support healthy creeks and reduce flooding by reducing stormwater runoff, (3) support economic health by protecting cultural and civic resources, and (4) support healthy lifestyles by improving livability and tourism. Specific actions include replanting stream buffers, planting more trees on public lands, selecting drought-tolerant trees for planting, adding permeable pavement and rain gardens on city properties to catch more runoff, and reducing impervious surfaces. The city plans to use the new land cover data to prioritize demonstration projects.

The EPA's Office of Water is providing funding for Tetra Tech to work with various communities across the United States to help them integrate climate change considerations into green infrastructure projects, helping enhance municipal resiliency while achieving other benefits. Tetra Tech has partnered with a variety of communities, including New Orleans, where it is collaborating with the city's stormwater manager to identify how green infrastructure projects and available funding can work synergistically with other city and sector planning activities and objectives. Tetra Tech and the city hope to collaboratively create a green infrastructure design that can help with flood control, stormwater management, and greenhouse gas mitigation, while helping create urban agriculture opportunities and enhancing community walkability. Design options are coming in part from a community stakeholder workshop, where Tetra Tech had community members explore their resiliency goals and ideas for given project sites, and then link these ideas to the larger cityscape to identify which projects would work well together. Tetra Tech has also evaluated climate-hydrological modeling data available for the region, and plans to integrate these projections into the final design to increase long-term project resilience and functionality. Funding for project implementation will have to come from the city itself.

Develop disaster preparedness plans and policies

Climate change may exacerbate natural disasters in the region, including droughts, floods, severe storms, and extreme heat events that will harm people, property, and water resources. Disaster preparedness and mitigation plans can help communities identify risks and develop response and recovery options.

In collaboration with AMEC, the City of Waveland, Mississippi, created and published a Local Hazard Mitigation Plan (LHMP) and subsequent plan updates in 2013 (AMEC 2013). Waveland developed the LHMP in order to make residents and property less vulnerable to natural hazards, including events that may be amplified by climate change (e.g., flood, drought). The LHMP includes: a risk assessment that identifies and profiles hazards (including drought, floods, and dam/levee failures); a vulnerability assessment that assesses the city's vulnerability to identified hazards; a mitigation strategy, outlining the city's capability to mitigate hazards; and definitive goals and objectives, prioritized in order of importance and impact, that will be implemented by local authorities to reduce the city's vulnerability. Many of these identified objectives are already underway. For example, 90% of the city lies in a special flood hazard area, so the city is implementing a $6.9 million dollar drainage project aimed at improving floodwater drainage. Updates to the LHMP reflect the city's changing vulnerability to different hazards, and are designed to maximize community points and credits for the National Flood Insurance Program.

The Gulf of Mexico Alliance (GOMXA) Coastal Community Resilience Team is helping local municipalities incorporate resilience into their planning, emergency and hazard mitigation plans. FEMA requires cities to update their emergency plans every five years in order to qualify for disaster assistance, and GOMXA is using this requirement as an opportunity to help cities explore and address their vulnerability and risk in relation to climate change. For example, GOXMA led a municipal resilience project in Biloxi, Mississippi, educating the community about sea level rise and helping update the city's hazard mitigation plan to incorporate sea level rise issues. Aside from increasing community resilience to sea level rise and stormwater problems, the updated hazard mitigation plan should also qualify Biloxi for National Flood Insurance Program (NFIP) Community Rating System (CRS)[33] points, which are given to communities who voluntarily engage in floodplain management activities that exceed minimum NFIP requirements. Earning CRS points is a key priority for many Gulf residents, as it reduces their flood insurance premium rates. By combining climate resilience with local NFIP CRS goals, GOXMA helps municipalities simultaneously meet the immediate needs of resident stakeholders and bolster long-term community resilience.[34]

[33] National Flood Insurance Program Community Rating System: http://www.fema.gov/national-flood-insurance-program-community-rating-system

[34] Gulf of Mexico Alliance, Coastal Community Resilience: http://www.gulfofmexicoalliance.org/our-priorities/coastal-community-resilience/

Regional Climate Adaptation Case Studies

EcoAdapt staff identified potential projects to be written as case study examples through interviews and surveys and reviews of online resources and publications. All of the case studies follow the same format and include similar information underneath each heading – *Project Summary*, *Project Background* (where and why the project started, project goals, cost and funding source, climate impacts of concern), *Project Implementation* (project process, resources and information used, stakeholder or outreach engagement), *Project Outcomes and Conclusions* (resources produced, anticipated and unanticipated outcomes, metrics for success, challenges and if/how they were overcome, next steps, lessons learned), and *References* (any resources used for or produced from the project). Case studies underwent internal and external peer review. This section presents 18 long-form case studies from our survey of climate adaptation activities in the Southeastern United States and U.S. Caribbean, including:

- Restoring Three Mile Creek via a Comprehensive Watershed Management Plan
- Statewide Efforts to Improve Water Resources Management in Alabama
- Climatic Variability and Water Supply Planning in Tampa Bay
- Planning for Change in Chatham County, Georgia
- Implementing Green Infrastructure to Enhance Stormwater Management in Louisville, Kentucky
- Enhancing Flood Resilience with the Greater New Orleans Urban Water Plan
- Inner Harbor Navigation Canal Lake Borgne Surge Barrier: Resilient Storm Surge Protection for New Orleans
- Using Advocacy to Enhance Gulf Coast Resilience
- Waveland's Climate-Informed Local Hazard Mitigation Plan Update
- Resilient Water Supply Planning at Orange Water and Sewer Authority, North Carolina
- Long-Range Water Supply Planning in the Town of Cary, North Carolina
- Upper Neuse Clean Water Initiative: Collaborative Land Protection to Maintain Water Quality
- Integrating Climate Change into Plan Revisions at Francis Marion National Forest
- Developing a Structured Decision-Making Model to Facilitate Adaptive Dam Management
- Identifying and Reducing Climate Risks to Water Resources in an Eastern Virginia Water Utility
- A Climate-Informed Update of Virginia's State Wildlife Action Plan
- Climate-Informed Watershed Restoration on the Elizabeth River
- Integrating Climate Change into Plan Revisions at El Yunque National Forest

Restoring Three Mile Creek via a Comprehensive Watershed Management Plan

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Project Summary

A comprehensive watershed management plan has been developed to help guide the restoration of Three Mile Creek, an urban watershed located near Mobile, Alabama. Three Mile Creek suffers significant non-point source pollution and sedimentation issues, and is also vulnerable to climate change impacts, including sea level rise and increasing storm surge. The Mobile Bay National Estuarine Program hired Dewberry, an environmental contracting firm, to develop a comprehensive watershed plan that addresses pollution issues and enhances the resilience of natural and built communities associated with the creek.

Project Background

Three Mile Creek is a 14-mile, tidally influenced urban stream that flows through the city of Mobile, Alabama. Three Mile Creek drains a fairly large urban area, and like many watersheds in coastal Mississippi and Alabama, has significant water quality issues related to non-point source pollution (i.e. trash, sewage pathogens, fertilizer/nutrients) and sedimentation, problems that are exacerbated by stormwater runoff and flood episodes. Due to its tidal influence, Three Mile Creek and adjacent natural and human communities are also vulnerable to saltwater intrusion, inundation, and changes in freshwater availability as a result of sea level rise and increasing storm surge and storm intensity. These issues have historically contributed to Three Mile Creek being viewed as a city liability rather than an asset.

In an effort to transform Three Mile Creek into a local amenity, the Mobile Bay National Estuary Program recently partnered with a variety of groups to develop a Comprehensive Watershed Management Plan (CWMP). The CWMP is designed to restore Three Mile Creek's hydrology and water quality, increase recreational and public access, protect and enhance public and natural resource health, enhance heritage and cultural watershed connections, and to incorporate climate adaptation principles to ensure watershed and community resilience. Dewberry led the development of the plan in collaboration with the Mobile Bay National Estuary Program, Mississippi-Alabama Sea Grant Consortium, local municipalities, and the public. Plan development cost roughly $750,000, including $16,000 from the EPA to specifically examine climate change impacts.

Project Implementation

The Three Mile Creek Comprehensive Watershed Management Plan integrates a variety of information to guide the resilient restoration of this urban creek. Using existing studies and reports, Dewberry compiled information on current watershed characteristics and conditions and identified major challenges facing the watershed. These challenges include: stormwater runoff, wastewater contamination, altered and degraded ecological characteristics, lack of access, and vulnerability to sea level rise and shifting storm frequency. These challenges were also confirmed and evaluated by the public. During plan development, Dewberry held a series of 13 public meetings to discuss current challenges and outline a desired future for the watershed.

The CWMP also integrates new data and modeling. Dewberry and partners conducted field studies to gather additional water quality data related to surface water, groundwater, and sediment; they also identified critical data gaps that need to be addressed in the future to enhance the CWMP, including pollutant loads and sources. Dewberry also conducted sea level rise and storm surge modeling to understand future watershed impacts related to climate change. The Sea Level Rise Affecting Marshes Model (SLAMM) was used to evaluate how sea level rise and erosion may affect habitat types and current land uses, and to identify best management practices (BMPs) that could be used to complement water quality goals in the watershed. SLAMM identified that non-tidal/cypress swamp and inland fresh marshes in the Three Mile Creek watershed were likely to be inundated under even the lowest sea level rise scenarios, and that saltmarsh, tidal flats, and open estuarine habitats were likely to expand with sea level rise. Dewberry also used the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model in combination with SLAMM to model how storm surge and sea level rise may interact to affect habitats and community flood risk, finding that existing infrastructure becomes increasingly vulnerable as sea level rises.

Current conditions, public opinions and values, and additional data and modeling results were then used to generate a list of recommended BMPs for the Three Mile Creek Watershed. Management recommendations were grouped into four categories: non-structural BMPs (e.g., education, invasive species removal), structural BMPs (e.g., low-impact development and green infrastructure projects), long-range sustainability projects (e.g., tidal marsh restoration, rolling easements), and recreation projects (e.g., greenways and blueways). BMPs were also assigned to different geographical areas of the watershed to reflect and meet site-specific challenges. These BMPs were ranked and prioritized by a Technical Committee and through an online survey, as well as compared to the EPA's Nine Elements of a Watershed Plan framework. Actions identified in the CWMP were also compared and integrated with the Mobile Bay

National Estuarine Program Comprehensive Conservation and Management Plan to ensure that the watershed actions help promote complementary management goals in the local estuary.

A resultant shortlist of prioritized actions for near-term implementation were selected and highlighted based on their ability to provide early and immediate benefits to water quality within the Three Mile Creek watershed. Six out of the nine suggested actions help enhance resilience, and two — tidal marsh restoration, and flood risk assessment and education based on sea level rise and storm surge modeling — are explicitly focused on climate adaptation.

Project Outcomes and Conclusions

The Three Mile Creek Comprehensive Watershed Management Plan was published in September 2014, and includes a 10-year implementation outline for prioritized restoration actions. The next challenge is to procure implementation funding. The plan outlines potential costs and funding mechanisms and sources for all prioritized actions; successful planning and implementation of all proposed strategies is projected to total well over $65 million. Strong regional partnerships amongst the community of Mobile, adjacent municipalities, the Mobile Bay National Estuary Program, and other stakeholders will likely be critical in securing funding for these various projects.

Similar to other comprehensive watershed management plans, the Three Mile Creek Comprehensive Watershed Management Plan is designed to be a living document. Monitoring is an integral component of the plan, and adaptive management based on monitoring results is highly encouraged. Dewberry recommends that project partners track progress and alter management strategies accordingly on an annual basis, as well as complete in-depth reviews of plan components and action effectiveness every 3-5 years.

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Statewide Efforts to Improve Water Resources Management in Alabama

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Project Summary

State agencies and regional stakeholders in Alabama are in the process of creating a state water management plan to ensure sustainable management of Alabama's water resources in the face of a growing population and increasing climatic variability. State-level actions include the formation of an interagency water-focused working group to lead the development of a state water planning process, an update to the state's Drought Management Plan, and new cross-agency efforts to increase and consolidate water resources monitoring to inform decision-making. The Alabama Rivers Alliance and other regional stakeholders are simultaneously lobbying for a state water management plan that integrates adaptive management, protects water supply for both natural and human communities, and reflects the values and opinions of Alabama stakeholders.

Project Background

Alabama faces several water resources challenges that may be exacerbated by an increasing population, economic development, and climatic variability. Although typically viewed as a water-rich state, Alabama has experienced six severe droughts since the 1980s, including a historic drought from 2006-2008. In addition, an increasing regional population is increasing demand for the state's existing water resources, and Alabama water supply is also affected by interstate water relationships, including reservoir management and water use in Georgia, Florida, and Mississippi. As future shifts in population and climate exacerbate Alabama's water supply and quality issues, Alabama's state government must balance water provisioning for both natural and human communities. To respond to these challenges and plan for a sustainable water supply future, both state agencies and nonprofit groups are striving to create and revise state-level water resources policy.

Several policy measures are being addressed via the state government. Periods of extreme drought, and recognition that future drought periods may increase in frequency and intensity, have led the Alabama Office of Water Resources to develop and update Alabama's Drought Management Plan. Additionally, Gov. Robert Bentley formed the Alabama Water Agencies Working Group in 2011. This multi-agency group has been tasked with helping to assess and improve the management of Alabama's water resources by developing an action plan and timeline to guide implementation of a state water resources plan.

Alongside these governmental efforts, nonprofit entities such as the Alabama Rivers Alliance are lobbying and gathering stakeholder support for a comprehensive, sustainable and adaptive state water management plan. In particular, the Alabama Rivers Alliance wants to: (1) build flexibility into the emerging policy to ensure that state management can respond to variable conditions, (2) encourage inclusive and proactive management of water supply for natural systems, and (3) integrate and increase stakeholder involvement in the state water management planning process.

Project Implementation

Government Action

Alabama Water Agency Working Group

After taking office in 2011, Gov. Bentley quickly formed the Alabama Water Agency Working Group (AWAWG) and officially formalized the group in early 2012. The AWAWG is comprised of six governmental agencies: the Alabama Department of Economic and Community Affairs, Alabama Department of Agriculture and Industries, Alabama Department of Conservation and Natural Resources, Alabama Department of Environmental Management, the Office of the State Climatologist, and the Geological Survey of Alabama. All of these agencies have some management purview in relation to state water resources. In April 2012, the AWAWG was charged by Gov. Bentley to develop a process and recommendations for a State Water Plan. Specifically, the AWAWG was tasked with identifying the issues surrounding state water resources management and, given the realities of water demand and supply, to develop water management strategies for the future.

In late 2012, the AWAWG published a report titled *Water Management Issues in Alabama*. This document provides an overview of Alabama's water resources issues, discusses relevant considerations and needs for each water issue area, and briefly outlines policy options. The report was designed to facilitate water resources discussions between stakeholders and to lay the framework for the development of a state water plan. In addition, the report highlights the need to incorporate land use change, population growth, economic development, hydrologic extremes, and climate change impacts into state water resources planning.

Following this report, the AWAWG engaged with stakeholders and began gathering relevant water resources data. To increase stakeholder buy-in and feedback, the 2012 *Water Management Issues in Alabama* report was circulated amongst 248 individuals and organizations, as well as presented and discussed at regional meetings and conferences prior to publication. AWAWG members also compiled relevant hydrological data and identified key information gaps that will be critical for informing future water management planning efforts.

Stakeholder input and relevant data were incorporated into a formal AWAWG report published in December 2013, titled *Mapping the Future of Alabama Water Resources Management: Policy Options and Recommendations*. This two-part report proposes a process and action plan — known as the Alabama Water MAP (Monitor, Assess, and Plan) — for the creation of a state water management plan, and integrates information generated at all previous stages, including an analysis of and proposed policy options for the 12 different water resources issue areas. It also investigates the intersection of and trends in water supply and demand, and highlights the importance of using science and data to better understand, predict, and manage state water. This report will help guide Alabama forward in creating a comprehensive statewide water management plan.

Office of Water Resources and the Alabama Drought Plan Update
Alabama's first State Drought Plan was created in 2004 as a result of an earlier executive order process that provided the structure for enhancing state-level communication and coordination during drought periods. Alabama had the opportunity to implement its Drought Plan in 2006-2008 during a historic drought event. Building on its experiences during the 2006-2008 drought, the state is now developing ideas and updates to improve that plan. For example, the Office of Water Resources (OWR) is in the process of developing a more rigorous state-based drought monitor, which will incorporate short- and long-term drought forecasting capabilities in addition to the real-time data provided by the national U.S. Drought Monitor. The forecasting data will be generated from a variety of sources, including trends in water availability, trends and changes in water demand (e.g., population growth or changes in sector use), local climatological conditions, and short- and long-term climate projections. By creating a state-based drought monitor with forecasting capabilities, the OWR hopes to provide water managers and users with a more holistic picture of water supply and risk, which can improve short- and long-term decision-making.

The OWR published a revised version of the Alabama Drought Management Plan in 2013. This revision includes a more specific outline of drought triggers, clarifies different interagency roles during drought periods, and continues to promote collaboration and communication between water managers and users. In addition, the Alabama Drought Planning and Response Act was signed into law on April 9, 2014, detailing the state government's role in planning, monitoring, and responding to drought conditions. This act formally establishes the Alabama Drought Assessment and Planning Team (ADAPT) and the Monitoring and Impact Group (MIG), mandates all public water systems within Alabama to create water conservation plans, improves protocols and requirements for reporting local conditions and water supply, and clarifies how the OWR will issue drought declarations. The Alabama Drought Planning and Response Act allows collaborative discussion and development of regulations surrounding drought, and ensures that state-based drought planning procedures can be easily integrated into comprehensive statewide water resources planning.

Stakeholder Action

Alabama Rivers Alliance Water Policy Lobbying

Regional stakeholders, such as the Alabama Rivers Alliance (ARA), are also actively engaged in helping shape state water policy. The ARA is particularly interested in helping the state develop water policies that are adaptive, stakeholder-informed, and that accommodate future variability and incorporate stream flow maintenance and protection parameters. These principles have been derived from continual discussions with many regional stakeholders, as well as from priorities outlined in the *Alabama Water Agenda*. This Agenda, originally published in 2008, was revised in 2011 based on a survey of over 60 watershed groups. It promotes four high-level systemic issues related to water management: (1) development of state and federal water policy that addresses water quality and quantity, (2) enforcement of water laws that currently exist, (3) adequate funding for water management agencies and activities, and (4) improvement of interagency water management coordination to prevent coverage gaps that could negatively affect water supply or quality.

Parallel to the state's planning efforts, the ARA has been advocating for instream flow requirements and developing suggested methodologies on how to prioritize and generate streamflow recommendations for vulnerable Alabama basins. The ARA has proposed that the state use the Regulated Riparian Model Water Code (developed by the American Society of Civil Engineers) in developing water policy. This code provides policy options primed for quick state adoption, is tailored to eastern states, and contains policy developed to help states manage water allocations and multijurisdictional water transfers, and to mitigate water use conflicts. It also prioritizes the precautionary principle and adaptive management.

In addition to the adoption of this code, the Alabama Rivers Alliance has also provided guidance on methods for generating streamflow recommendations. Alabama has over 132,000 stream miles, and the ARA recognizes that the state government needs a cost-effective method for generating streamflow requirements. ARA has proposed that the state first should adopt a presumptive streamflow standard to help identify which streams are in most critical need of enhanced management oversight. For example, the state could compare contemporary and historic streamflows, and flag streams that have experienced a 10% or greater hydrological alteration. These impaired streams can then be run through the Ecological Limits of Hydrological Alteration (ELOHA) model. This model helps identify streamflows necessary to maintain critical ecologic function, and provides policy guidance to help achieve river condition maintenance and management goals.

In partnership with several state universities and various stakeholder groups including the Alabama Farmers Federation and the Alabama Chapter of the Sierra Club, the ARA has also led a series of stakeholder Water Symposia meetings to discuss water issues and water science, and to more clearly outline what stakeholders expect from the Alabama state water management plan. These meetings have also been used to brainstorm what adaptive water management may look like under the Riparian Code.

As the planning process moves forward, ARA will transition this effort to a university consortium consisting of the University of Alabama, Auburn University, and Troy University to continue these stakeholder meetings as part of the AWAWG public outreach effort. Continuation of these stakeholder meetings will allow for the integration of stakeholder participation into state-level planning, which will help inform the development of an amenable and resilient state water management plan.

Project Outcomes and Conclusions

Building upon the AWAWG efforts and the new Drought Management Plan, the state of Alabama plans to continue to investigate and better understand the challenges and risks surrounding water resources management. At the direction of Gov. Bentley, the state convened stakeholders into a series of "focus area panels" to "deliberate key issues and submit reports to the AWAWG" in the areas of (1) Riparian Rights and Other Legal Issues, (2) Instream Flows, (3) Local and Regional Planning, (4) Certificates of Use, Permitting, and Interbasin Transfers, and (5) Water Conservation, Efficiency, and Reuse. ARA is one of many stakeholders participating on these panels, which span the spectrum of water interests in Alabama. At the conclusion of this process, the state hopes to develop informed water policy that is economically and environmentally responsible. Ideally, final state policies will allow for population and economic growth while protecting natural resources, including water quality, flow, and aquatic habitat. In the interim, the state hopes to use its Drought Management Plan to be better prepared and more effectively coordinate water supply issues related to drought conditions.

The AWAWG has stimulated significant activity and dialogue amongst state water agencies. For example, the Alabama Department of Economic and Community Affairs (ADECA), Office of Water Resources (OWR), and the Alabama Geological Society (AGS) are working collaboratively to assess the availability, demand, and projected changes for groundwater and surface water in Alabama. By analyzing historical data, trends, and projections regarding water availability and use, this project will hopefully provide a high-resolution view of the state's water supply, helping inform policy and development of a statewide water management plan. This project may be able to help managers identify where and why water shortages have occurred in the past, and where they are likely to occur in the future (e.g., areas where demand may exceed availability), allowing them to proactively manage and mitigate those situations. Assessing current water supply also lays the foundation for future incorporation of intra- and inter-annual climate variability, which would add another layer of analysis to the larger picture of water supply within the state.

The Alabama Rivers Alliance and other regional stakeholders hope to work with the state to further enhance stakeholder involvement in the state water planning process and to maintain momentum for adaptive policy development. They are continuing to engage key regional players, and are also collecting annual feedback on state water user needs by holding an annual conference. The ARA hopes to bring this information, as well as lessons learned by monitoring other states' issues and efforts (e.g., Georgia), to decision-makers in order to guide policy development that reflects shifting landscape conditions and needs. Throughout this process, ARA continues its parallel work aimed at improving water pollution policy in the state.

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Climatic Variability and Water Supply Planning in Tampa Bay

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Project Summary
Tampa Bay Water is a drinking water utility servicing over two million residents in Hillsborough County, Pasco County, Pinellas County, New Port Richey, St. Petersburg, and Tampa. The utility is working to assess how climate change will affect local hydrology and water supply, provide forecasting tools to inform decision making, and diversify water supply sources in the region.

Project Background
Tampa Bay Water is one of the eleven members of the Water Utility Climate Alliance, a collaborative focused on advancing climate resilience in water utilities throughout the United States. The utility has been working to assess how climate variability will affect local water supply, especially with respect to seasonal forecasting and periodic droughts. Historically, the region relied exclusively on groundwater pumping for its supply; however, saltwater intrusion and overpumping in the 1980s triggered a shift to 60% surface water supply from local rivers and the bay itself. However, the 1999-2001 drought required the utility to again pump groundwater to match consumer demand; the extent of this extraction had major impacts on the surrounding natural environment. The region is experiencing increasingly higher seasonal climatic variability, which may drive even more frequent droughts; at the same time, water demand will increase as the regional population grows. Tampa Bay Water believes its system is robust for another 15-20 years, but knows it needs to start planning for future demands. For example, the utility currently supplies approximately 240 million gallons per day (mgd) on average to over 2.4 million residents; projections indicate that with an increasing population, demand will increase to 275 mgd by 2035.

Project Implementation
Tampa Bay Water is engaged in a number of efforts to provide resilient drinking water supplies, primarily (1) using forecasting tools to inform decision making, (2) conducting an assessment of the effects of climatic variability local hydrology, and (3) diversifying water supply sources in the region.

Forecasting
Using the Climate Outlooks from NOAA's Climate Prediction Center, the utility tracked patterns in the El Niño Southern Oscillation (ENSO) to forecast wet and dry conditions in the region. These outlooks are useful to local water managers to identify near, short-term changes in

surface water availability, and make strategic decisions on groundwater withdrawals to meet immediate consumer demands.

Climatic variability and water supply
Recognizing the need to forecast water supplies more reliably and over a longer timeframe, Tampa Bay Water partnered on a project to assess climate impacts on the area's water supply and the utility's ability to meet an anticipated increase in demand. The objectives are to evaluate the ability of dynamical and statistical downscaled Global Climate Models (GCM) to reproduce observed regional temperature and rainfall patterns; reproduce historic hydrologic behavior; evaluate projected changes in hydrology associated with future projections of temperature and rainfall; and assess the effects of climate projections on future water supply availability in the region. Initial results demonstrate high variability in projected precipitation patterns, which indicates a need for more refined regional and local hydrologic-climate models.

Diversified water supply sources
The utility constructed a $158-million desalination plant to protect groundwater sources from saltwater intrusion, as well as a $140-million, 15-billion-gallon reservoir that stores water from the Alafia River, Hillsborough River, and Tampa Bypass Canal. These measures provide back up water supply during periods of drought, including during the recent April 2017 drought.

Project Outcomes and Conclusions
Tampa Bay Water is also collaborating with the Florida Water and Climate Alliance on projects to evaluate the effects of sea level rise on groundwater well and surface water quality, and the impacts of temperature changes on potable water delivery and operation and maintenance of water resources infrastructure.

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Planning for Change in Chatham County, Georgia

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Project Summary

Chatham County is vulnerable to sea level rise, flooding, and erosion. Increasing the ability of the county to adequately prepare for and recover from the impacts of climate change are important goals of the Chatham County – Savannah Metropolitan Planning Commission. These goals have expanded into ensuring that all areas of the county are preparing for climate change, including public works, fire departments, hospitals, board of educators, and county engineers. The county sees itself as a driver for sustainability for all sectors in Chatham County and is acting as a pilot program for the rest of the state to learn from and follow. As a result of a 2010 climate change planning workshop, the county released an updated comprehensive plan in 2017 to guide development decisions over the next twenty years.

Project Background

Chatham County is located along the Atlantic Coast in Georgia. In March 2010, county officials convened a workshop with the NOAA Coastal Services Center to discuss climate change threats and develop a roadmap for action. The Roadmap for Adapting to Coastal Risk is a training module developed by NOAA to help cities and counties integrate current and future hazard considerations into local planning and decision making. Local officials, staff, and concerned citizens attended the workshop and discussed the threats and vulnerabilities associated with climate change on Chatham County and coastal Georgia. This included education on the specific threats to coastal Georgia and its shifting climate patterns.

Part of the workshop included discussing existing strategies as well as identifying potential future strategies for major threats, including sea level rise, storm surge inundation, coastal flooding, and erosion.

- Sea level rise. There are no current actions being taken to address sea level rise, although key strategies to pursue include understanding how saltwater intrusion will affect natural systems and human communities and establishing long-range policies to minimize damage in vulnerable coastal areas.
- Storm surge inundation. The county is currently depending on dredging to protect the coastline, although future strategies discussed include developing and maintaining natural infrastructure to buffer the shoreline.
- Coastal flooding and erosion. Currently, the county is building more roads and stormwater pumping stations at higher elevations. Potential future strategies include investing in green and open space and public transit. In terms of erosion, development

is currently allowed right on the beaches in the area. A key future strategy is to establish a new sand dune protection line based on sea level rise scenarios and hurricane-related storm surge projections.

Additionally, the county considers its application of smart growth principles (i.e. mixed land uses, open spaces), green infrastructure, and flood and hazard mitigation to help make the area more resilient to climate change. As a result of the workshop, Chatham County started working to develop strategies on how to start addressing them in the county's Comprehensive Plan.

Project Implementation

The county updated its comprehensive plan to examine how to integrate climate-informed principles into growth and development decisions over the next 20 years. The county included sea level rise in the update, but at the local level, sea level rise has been a controversial topic and the county has had to be very careful on how to handle it. The county has incorporated it throughout the comprehensive plan more as a flooding issue, since there are many flooding problems in the area. The plan took quite a long time to update due to issues in prioritizing strategies. Climate adaptation objectives in the plan include: identifying the areas of the county that may be vulnerable to sea level rise; expanding planning horizons for sea level rise adaptation to capture the anticipated impacts based on current models; drafting a regional sea level rise plan; and requiring consideration of climate adaptation and sea level rise in existing and planned, public and private infrastructure and land development.

Project Outcomes and Conclusions

Chatham County is now updating its zoning ordinances and subdivision codes to prioritize low impact development and green infrastructure as part of resilience planning. In addition, all the municipalities in Chatham County have updated their stormwater policies and adopted the Coastal Stormwater Supplement of Georgia's Stormwater Management Manual. The supplement addresses ways to address flood vulnerabilities in development efforts to protect and maintain the integrity of local aquatic resources. It includes design recommendations to help protect local aquatic resources, reduce flooding through post-construction stormwater management and site planning design, and improve water quality through green infrastructure.

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Implementing Green Infrastructure to Enhance Stormwater Management in Louisville, Kentucky

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Project Summary

In response to combined sewer overflows, stormwater quality issues, and regional flooding in Louisville, Kentucky, the Louisville and Jefferson County Municipal Sewer District (MSD) has implemented a variety of green infrastructure projects to help capture and infiltrate stormwater. Projects include 19 green infrastructure demonstration projects, two combined sewer overflow drainage area projects, and a green infrastructure financial incentives program. As a part of the incentives program, several large green infrastructure projects have been implemented on the University of Louisville campus to minimize university flood risk and reduce stormwater delivery to the combined sewer system. Water quality treatment and green infrastructure design standards as well as lessons learned from these citywide green infrastructure projects are discussed in the MSD's online Green Infrastructure Design Manual, a free resource that outlines green infrastructure options and provides guidance on how to use green infrastructure to meet permitting requirements (e.g., MS4 stormwater permits).

Project Background

The Louisville and Jefferson County Metropolitan Sewer District (MSD) operates a combined sewer and stormwater system in Louisville, Kentucky. Recurring overflows of this system caused the EPA to issue a consent decree for the MSD in 2005; this decree requires the MSD to invest roughly $850 million to improve the city's sewer system and mitigate sewer overflows. The MSD developed and adopted the 2009 Integrated Overflow Abatement Plan in order to guide response to the consent decree. As a part of a metro-wide effort to meet stormwater permit requirements and mitigate sewer overflows, the MSD also established a water quality treatment standard in 2013, requiring developments of one acre or greater to mitigate stormwater with green infrastructure. Overall, the MSD's goal is to implement green infrastructure projects that improve water quality, help reduce stormwater delivery to the combined sewer system, and reduce the demand for and role of gray infrastructure (i.e. conventional infrastructure built of materials such as concrete and steel). This program of work is particularly timely, as the region is experiencing increased flooding as a result of high-intensity rainfall events.

Flooding is of particular concern for the University of Louisville. The university campus experienced severe flooding in 2009, causing over $21 million in damage to 92 different campus buildings. Given current impacts and concern about increasing flood risk associated with climate change, the University of Louisville has partnered with the MSD to implement extensive green infrastructure projects and reduce stormwater delivery to the combined sewer system. The university has received roughly $1.25 million in MSD funds and some university funds to implement a variety of stormwater management projects. These green infrastructure projects are part of a larger university-wide effort to address climate change.

Project Implementation

As a part of its Integrated Overflow Abatement Plan, the MSD initially began testing and exploring the effectiveness of green infrastructure in reducing stormwater runoff through 19 different demonstration projects, including installation of permeable alleys and parking lots, rain gardens, and green roofs. Pre- and post-construction sewer flow data were collected and compared for these projects, and the MSD learned many valuable lessons throughout design, construction, and monitoring phases. These lessons learned were combined with a system-wide modeling effort to assess the placement and feasibility of green infrastructure to reduce or replace gray infrastructure basin projects identified in the Integrated Overflow Abatement Plan, eventually leading to on-the-ground projects using green infrastructure techniques at a larger scale and greater density. For example, in the CSO 130 basin, the MSD was able to successfully replace a gray infrastructure basin with green infrastructure solutions, including permeable pavers and tree boxes. These projects captured and stored enough stormwater volume to completely eliminate the need for a combined sewer basin. Lessons learned from the sewer overflow drainage area projects and the 19 green infrastructure demonstration projects facilitated the creation of the MSD's Green Infrastructure Incentives Program. This program provided funding for private property owners to install green infrastructure on their land. Cost varied by project, but generally ran from $1-$1.50 per square foot of impervious drainage area. Drainage areas with the most overflows, as well as basins modeled to be most likely to benefit from green infrastructure installations, were prioritized for project implementation. By incentivizing and installing green infrastructure on private land, the MSD hoped to reduce the contribution of stormwater runoff to the sewer system, thereby reducing combined sewer overflows and the size of necessary gray infrastructure capture basins.

As an example of projects implemented using incentives, the MSD partnered on numerous green infrastructure projects on the University of Louisville campus. After severe flooding caused extensive facility damage in 2009, the University of Louisville decided it needed to engage in sustainable stormwater management, including mitigation and adaptation efforts, to help reduce campus flood risk. The university was one of the first groups to partner with the

MSD on green infrastructure projects. Installing green infrastructure projects on campus — including underground infiltration chambers, cisterns, and permeable pavers — helped to mitigate flood risk to both the university and the metropolitan area by reducing stormwater delivery to the area's combined sewers during high rainfall periods.

Stormwater management efforts also tie into the university's larger climate change advocacy and action items. The university's climate work started in 2008 when the university president signed the American Colleges and Universities Climate Commitment, which pledges to reduce greenhouse gas (GHG) emissions to net zero and to educate the college community about the significance of climate change. The university formed an institution-wide sustainability council to implement the commitment; the first year was spent documenting university GHG emissions, and the subsequent year was spent creating a Climate Action Plan. Published in 2010, this Plan identifies over 175 different options for reducing university emissions and enhancing adaptation, including components related to stormwater management. For example, the campus master planning chapter suggests minimizing unnecessary hardscape and planting native, deep-rooted tree species to enhance carbon sequestration and help manage stormwater. Similarly, the transportation chapter promotes student use of alterative transportation methods, including biking, walking, and taking public transit. In the absence of using these alternative transportation options, an increasing student population may drive increased demand for parking structures, which often elevate stormwater runoff.

Using lessons learned through partnership projects with the EPA Office of Research and Development, University of Louisville, and others, as well as lessons learned from the green infrastructure demonstration projects and the Green Infrastructure Incentives Program, the MSD updated its Green Infrastructure Design Manual. This manual outlines various green infrastructure options, and provides guidance on how users can meet various regulatory requirements using green infrastructure. Contents of this manual were drawn from on-the-ground experience as well as from other regional sources, including resources from the Center of Watershed Protection, MSD's participation in the 5 Cities Plus group, a collaborative of utility industry executives who meet to share ideas and best practices for compliance with federal laws and regulations, and MSD's participation in regional stormwater conferences.

Louisville MSD also adopted updates to the Wastewater/Stormwater Discharge Regulations effective in 2013, which enabled creation of a Fee in Lieu program for land parcels and development projects where installing green infrastructure is not feasible. Options for program qualification and implementation are currently being reviewed and considered by the MSD, including infiltration capacity, presence of sinkholes or karsts, or other factors that could limit green infrastructure effectiveness or feasibility.

Project Outcomes and Conclusions

Louisville MSD and partners have successfully implemented a number of green infrastructure projects within Jefferson County since the EPA Consent Decree in 2005 (amended in 2009) and 2009 Integrated Overflow Abatement Plan. On the University of Louisville campus, numerous green infrastructure features have been installed since 2010, including underground filtration systems, green roofs, permeable pavers, rain barrels, and stormwater collection cisterns. The university has also actively been disconnecting downspouts and parking lots and driveways from the sewer system. The university's green infrastructure system currently diverts about 75 million gallons of stormwater per year, and helped minimize flooding during a recent severe storm in 2012. In addition, since publication of its Climate Action Plan, the university has reduced its GHG emissions 27%. The MSD's Green Infrastructure Incentives Program is now transitioning its focus to target drainage areas with the highest overflow risks. The MSD are also working with a variety of partners to monitor flow and water quality in basins with implemented projects to better understand the quantitative impact of green infrastructure in reducing stormwater delivery to the combined sewer system and regional rivers and streams. In addition, since original publication, the Green Infrastructure Design manual has undergone updates and revisions to reflect changes in MSD rules and regulations. For example, the manual was revised in 2013 to reflect and provide guidance on meeting the MS4 Stormwater Permit requirements. MSD requires new and redevelopment projects of one acre or greater to capture and treat the first 6/10 of an inch of rainfall with green infrastructure. This manual is publically available online, and the MSD has recently expanded its website to increase communication about green infrastructure benefits with the public.

Moving into the future, Louisville MSD hopes to use monitoring information and emerging information from academic research and regional projects to continually revise its Green Infrastructure Design Manual. MSD is also engaged in projects to minimize flood risk, including buyouts of flood-prone buildings, and upgrading floodwater storage basins to accommodate higher flows and then gradually release them as water levels recede. The University of Louisville is also hoping to increase monitoring of its green infrastructure projects, as well expand education, outreach, and visibility of these projects. Many of the implemented green infrastructure projects are not visible (e.g., underground infiltration basins). By enhancing the visibility of these and new projects in the future, the university hopes to promote the integration of sustainability actions more thoroughly across all campus facilities and communities, and to use these sustainability successes for university marketing and fundraising. Alongside its stormwater adaptation work, the university also hopes to reach emission neutrality by 2050.

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Enhancing Flood Resilience with the Greater New Orleans Urban Water Plan

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Project Summary
The Greater New Orleans Urban Water Plan is a 50-year plan that proposes to use water system upgrades and urban design projects to reduce flood risk and improve stormwater, surface water, and groundwater management in New Orleans, Louisiana. By creating an integrated living water system, the plan will enhance the quality of life for New Orleans residents, help create viable wildlife habitat, and enhance the resilience of the city in the face of climate change. The plan was developed by a diverse project team, and incorporates ideas from Dutch frameworks for water management. Project partners hope that this plan will not only reduce flood risk in New Orleans and slow rates of local land subsidence, but also help the city transition from viewing water as a liability to viewing water as a community asset.

Project Background
The City of New Orleans, Louisiana, faces significant water challenges. New Orleans is located in the Mississippi River Delta, and more than half of the city is below sea level, making it vulnerable to both rainfall-related flooding and storm surge. Rainfall-related flooding is projected to cost the region more than $8 billion over the next 50 years, in addition to costs associated with flood damage as a result of sea level rise and storm surge.

Current management practices and infrastructure exacerbate these flood risks. For example, the city currently pumps all stormwater out of the city, which limits groundwater infiltration and exacerbates land subsidence trends. The city has an extensive levee system, but the long-term costs to maintain these systems are extremely high, especially as system integrity is threatened by rising sea levels and high rates of land subsidence. In general, New Orleans currently views water as a liability rather than a municipal asset.

To address these issues and reduce flood risk for the city, regional partners are collaborating to redesign how New Orleans perceives and manages water through an integrated water management plan. In 2010, the State of Louisiana's Office of Community Development Disaster Recovery Unit provided funding via Disaster Recovery funds from a federal Community Development Block Grant sponsored by the Department of Housing and Urban Development. Greater New Orleans Inc. administered the $2.5 million in funding, selecting Waggoner & Ball Architects and their assembled design team to lead plan development. Plan implementation is being funded separately.

Specific goals in developing this plan were to: (1) refashion the New Orleans-water relationship to reflect the specific condition of living in a delta, (2) establish a regional water management authority to improve cross-jurisdictional management of stormwater and groundwater, and (3) to conduct system retrofits and implement urban design projects to slow and store stormwater, circulate surface water, recharge groundwater, create vital water-based public spaces, and incorporate natural elements and processes into the operation of an integrated living water system.

Project Implementation

In Fall 2011, Waggonner & Ball Architects was selected to lead the creation of the Greater New Orleans (GNO) Urban Water Plan. Waggonner & Ball assembled a diverse planning team and leveraged previous collaboration efforts to inform plan development. For example, the planning team included local, regional and international participants, including partners from the Netherlands. Similar to New Orleans, Dutch cities face significant flood risks, but have used natural and engineered solutions to manage these challenges and prepare for up to a 10,000 year flood event. In addition, Dutch drainage systems are designed to be a part of the public sphere, to enhance quality of life, and to create viable wildlife habitat. Prior to beginning work on the GNO Urban Water Plan, David Waggonner (president and principal of Waggonner & Ball Architects) helped organize a series of "Dutch Dialogues" workshops to facilitate idea and knowledge sharing between Dutch engineers, urban designers, landscape architects, city planners, soils and hydrology experts, and other professionals and their New Orleans counterparts to begin addressing water management issues in New Orleans. The results of these workshops were further developed through the GNO Urban Water Plan.

Over the two-year plan development process, the planning team engaged in a variety of studies and inter-sector dialogues to ensure that relevant information and adaptive capacity were incorporated into the GNO Urban Water Plan. The planning team met with system operators, held design and planning workshops, and held meetings focused on examining technical topics related to subsidence, geomorphology, finance, existing infrastructure, and other themes. The team specifically analyzed how changing rainfall patterns may affect stormwater management and 5/10/50 year flood events in the city by incorporating higher precipitation levels (5% higher than current average) in all modeling efforts. By anticipating climate-driven shifts in annual rainfall, the team was able to design project and plan components that take into account potential increases in precipitation that would further elevate flood risk. In addition, the team studied the history of New Orleans to better understand how social perception and management of water has changed over time.

The planning team also engaged in significant public outreach efforts. At the beginning of the project, the planning team conducted nine outreach sessions with parish and community leaders. Prior to plan publication, the team also held four large public presentations and meetings to provide basic education about the plan, reaching roughly 600 people across three parishes. The planning team also engaged regularly with a stakeholder advisory council, which provided critical insight throughout the project duration.

Project Outcomes and Conclusions

The Greater New Orleans Urban Water Plan was published in 2013. It outlines a 50-year program of system retrofits and urban design opportunities for achieving a safer and more sustainable balance between land and water systems in the city. By creating an integrated living water system, the GNO Urban Water Plan will allow natural infiltration of stormwater to balance groundwater levels and slow subsidence and provide improved aquatic habitat for wildlife, and will also integrate water into public space. For example, the development of water-based public space, such as canal-side parks or publicly accessible wetlands, can be used to shift the public's perception and relationship with water while simultaneously providing environmental and adaptation benefits.

The GNO Urban Water Plan is tailored to a variety of professionals. It consists of three published components: (1) a Vision volume, which gives an overview of the entire plan; (2) an Urban Design volume, which was written for planning and design professionals; and (3) an Implementation volume, which was written for policymakers, water system managers, and other stakeholders. This plan is available online, along with a series of other reports generated through the plan development process. These resources include: system design and analysis reports related to water systems, groundwater, and ecosystem services; case studies of seven demonstration projects; and urban design and system analyses, which outline opportunities for adapting existing canal, road, and transportation infrastructure across multiple project scales.

The GNO Urban Water Plan covers St. Bernard Parish and the east banks of Orleans and Jefferson Parishes. The plan area reflects local hydrology rather than political boundaries, and includes three hydrologic basins. Organizing the plan based on hydrology facilitated collaboration between different parishes by avoiding typical political hot topics and focusing on shared hydrological issues. In addition, the plan focuses on urban water (including stormwater, surface water, and groundwater), as the USACE is undertaking a separate effort to address storm surge. A majority of the plan leverages existing infrastructure, proposing system upgrades and changes to operation rather than complete replacement, in order to better manage stormwater and reduce flood risk.

In the near term (5-6 years), project partners are focusing on implementation of various plan components. These pilot projects will help increase public education, demonstrate plan principles, and help fine-tune various plan components to reflect unique New Orleans soil and hydrologic conditions. Funding for implementation must be secured separately, but the city has found several funding streams to begin project implementation. New Orleans was selected as one of the Rockefeller Foundation's "Re-Invest" Initiative Cities, and received roughly $2 million from the foundation to begin implementation. In addition, New Orleans has received roughly $80 million in FEMA Hazard Mitigation funds for local neighborhood infrastructure improvements and hazard mitigation. Projects currently being implemented include: installation and monitoring of a network of bioswales and rain gardens in the Pontilly neighborhood; transformation of five vacant lots around the city into rain gardens to test green infrastructure principles and monitor changes in runoff; and construction of a linear park along the Lafitte Greenway/Blueway, the first step in a larger project to restore hydrological connectivity between different parts of the city and bring water back into the public sphere. The city received FEMA funding approval for a large project called the Mirabeau Water Garden, which aims to bring stormwater on to one of the city's largest undeveloped parcels to demonstrate neighborhood-scale water retention measures and infiltrate stormwater, as well as serving as a public recreation facility. This project was identified in the GNO Urban Water Plan, and will be a flagship project for the city once completed.

Funding for these and other large projects are actively being pursued by the New Orleans Redevelopment Authority and the Sewerage & Water Board of New Orleans, along with several municipal departments, including the Mayor's Office, the Office of Resilience, and the Department of Public Works. Despite this positive progress, significantly more funding will be needed for complete plan implementation; plan developers estimate that total plan implementation will cost roughly $6 billion. Although federal and other grants can help reach this goal, New Orleans must also proactively invest in its own infrastructure by promoting a thriving economy and developing internal funding streams for resilient stormwater management.

While city officials pursue larger-scale funding, many organizations throughout New Orleans are striving to promote adoption of GNO Urban Water Plan principles and to increase public education and outreach around stormwater issues. For example, the Greater New Orleans Water Collaborative has brought 30-40 nonprofit organizations together to conduct demonstration projects, further policy research, and conduct outreach, education and advocacy. In addition, Groundworks New Orleans is hosting job trainings related to green infrastructure careers, and Ripple Effect is working with local schools to educate K-12 students about water systems through design-based curriculum. These local grassroots efforts promote shifts in cultural perceptions of water and also help create public backing for city investment in stormwater projects.

Moving forward, project partners hope to increase communication and collaboration with public agencies to integrate the GNO Urban Water Plan into policy, and to help parishes develop new comprehensive zoning ordinances that will facilitate stormwater management. One challenge facing this process is that there is currently no legal force behind the GNO Urban Water Plan. The State of Louisiana funded plan development, but there is no local body directly responsible for plan implementation. In addition, New Orleans has no central authority for managing both stormwater and groundwater; rather, each jurisdiction (e.g., parish) does so independently. With no one in charge, and without a formal incentive to manage water in an integrated way, implementing the GNO Urban Water Plan will require significant structural reform. However, current collaborative efforts on both the municipal and grassroots level prove this isn't impossible, and all groups are working hard to identify their roles and capacity for the future.

Throughout this process, project partners have found that incorporating city history and engaging the public has facilitated success in communicating the principles of the plan. In trying to shift public perception from water as the enemy to water as an amenity, the project team highlighted how water was the founding feature of New Orleans. Canals were used to connect the Bayou St. Johns to the French Quarter, and homes and public gatherings were oriented around local waterways. Further, some of the most vibrant parts of contemporary New Orleans, including Bayou St. Johns and public parks, revolve around existing water bodies. The project team uses its public outreach to demonstrate how the GNO Urban Water Plan can help enhance local identity and quality of life.

Moving into the future, the project team hopes to change the way New Orleans operates in relation to water. From a policy standpoint, the team hopes that in the next 15-20 years, pilot projects from the plan will transition to city-wide changes, leading to alterations in design standards and public works projects that improve the management of stormwater and reduce flooding. During the planning process, each city pump station was assigned a specific volume of water it would have to pump given a 10-year storm event, with higher numbers reflecting a higher flood risk for the adjacent area. The team is currently tracking water assignments at different pump stations in the city, and hopes that as projects and policy measures are implemented, water assignments at each pump will drop to zero, representing mitigated flood risk. Currently, there is limited funding to continue this monitoring, and there is no review process in place for future evaluations of the plan's effectiveness. The project team aspires to secure funding within the next several years to finance continued monitoring of municipal pump stations and to design and implement an plan review process in order to incorporate lessons learned and to keep the GNO Urban Water Plan up-to-date with changing needs and conditions as the city and the region evolve.

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Inner Harbor Navigation Canal Lake Borgne Surge Barrier: Resilient Storm Surge Protection for New Orleans

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Project Summary
The Inner Harbor Navigation Canal Lake Borgne Surge Barrier, the largest civil engineering project in the history of the USACE, was designed to reduce storm surge and flood risk for New Orleans after devastating flooding during Hurricane Katrina. The 26-foot-high, 10,000-foot-long storm surge barrier minimizes 100-year flood risk, and features three navigational gates that can be raised in anticipation of storm surge. One of these gates, designed by Tetra Tech, is also buoyant, which extends the lifespan of the structure by allowing it to adjust to storm surge changes associated with sea level rise.

Project Background
During Hurricane Katrina, southeastern Louisiana experienced an 18-foot storm surge that overpowered floodwall and levee structures along the Mississippi River Gulf Outlet and Gulf Intercoastal Waterway, leading to floodwaters 15 feet deep inundating many neighborhoods in and surrounding New Orleans. Post-Katrina, the state and nation recognized the need for enhanced storm surge and flood protection for this area, particularly as climate change may exacerbate these risks. The confluence of the Gulf Intercoastal Waterway and Mississippi River Gulf Outlet was identified as an area of enhanced vulnerability; storm surge passes through this natural funnel in the coastline, ushering water inland towards the New Orleans inner harbor and municipal area.

In 2006, Congress authorized the USACE to design and implement the Inner Harbor Navigation Canal Lake Borgne Surge Barrier. The USACE was tasked with designing this storm damage risk reduction system to achieve 100-year risk reduction for the region (i.e. to protect against a storm surge that has a 1% chance of occurring in any given year). Specifically, the barrier was to be placed near the confluence of the Gulf Intracoastal Waterway and the Mississippi River Gulf

Outlet to protect the New Orleans area from storm surge originating from the Gulf of Mexico, Lake Borgne, and Lake Pontchartrain. The barrier also needed to maintain navigational passage.

Funding for the barrier came from the American Recovery and Reinvestment Act of 2009, and total cost for the project was close to $1.1 billion. The USACE granted a construction contract to Shaw Environmental and Infrastructure, Inc. in 2008, and Tetra Tech was hired as a subcontractor, along with Ben C. Geriwick, Inc., to lead the storm barrier design, as well as for their engineering services during construction.

Project Implementation

Tetra Tech led the design of the Inner Harbor Navigation Canal Lake Borgne Surge Barrier. Initial project design considered navigational needs and hydrological realities of the area, resulting in a final design that features a massive floodwall with three gates that permit navigational passage. These gates can be raised in response to storm surge, helping minimize flood risk while maintaining navigational opportunities. Gates include a 150-foot-wide sector gate across the Gulf Intracoastal Waterway, which is responsible for protecting New Orleans from Gulf of Mexico storm surge; a 56-foot-wide lift gate at Bayou Bienvenue that supports a vehicular bridge, and which protects against storm surge from Lake Borgne; and the Seabrook floodgate that protects against storm surge entering the Inner Harbor Canal from Lake Pontchartrain.

The final barrier was designed to meet a 50-year life span under “current conditions.” Sea level rise and storm surge projections associated with climate change were also referenced during the design process. Halfway through the design phase, an engineering review was completed, and several project components were adjusted to maximize barrier effectiveness, minimize construction costs, and reduce long-term maintenance requirements. Most notably, the sector gate spanning the Gulf Intracoastal Waterway was changed from a fixed gate to a buoyant gate by replacing the support wheels with buoyancy tanks. Minor adjustments were also made to Bayou Bienvenue lift gate.

Construction began in May 2009, and project contractors were tasked with reducing flood risk to surrounding communities by 2011. This aggressive timeline required design and construction to occur simultaneously, a unique reality for such a large infrastructure project.

Project Outcomes and Conclusions

The Inner Harbor Navigation Canal Lake Borgne Surge Barrier is the largest civil works project in USACE history. The final structure, completed in 2013, is a 10,000-foot-long and 26-foot-high concrete wall that provides complete closure of the Mississippi-Gulf Outlet. It features three navigational/storm surge gates, including the buoyant gate designed by Tetra Tech. This innovative buoyant gate adds an extra layer of resiliency to the surge barrier project, as it can rise in response to increasing sea level, thereby protecting against higher storm surge that may occur as sea levels rise. By accommodating changing conditions, the buoyant gate slightly extends the life of the structure beyond the 50-year design mandate. In addition, this novel design minimizes maintenance requirements and reduces overall operational stress on the structure.

The surge barrier project has received several awards, including the American Society of Civil Engineers 2014 Outstanding Projects and Leaders Award. Tetra Tech also received the American Council of Engineering Companies 2012 Grand Conceptor Award for the buoyant gate concept.

Construction of this surge barrier effectively reduced 100-year flood risk for the surrounding communities, and the buoyant gate enhances the project's resilience in the face of climate change. The surge barrier also relocated the focal point of flood protection infrastructure away from the city center of New Orleans, eliminating the need to raise 30 miles of existing flood-protection infrastructure, including levees and floodwalls. Although construction was not completed until 2013, the Inner Harbor Navigation Canal Lake Borgne Surge Barrier helped protect New Orleans from storm surge flooding associated with Hurricane Isaac in 2012. The full effectiveness of this barrier in reducing storm-surge associated flood risk will be tested during the next major hurricane.

One of the most significant challenges encountered in this project was the unique and complex hydrological and ecological nature of the Delta region. Saltwater and freshwater flooding are both major issues for New Orleans, making comprehensive flood risk reduction difficult. While the storm surge barrier will help enhance saltwater flood resilience stemming from the Gulf and regional bayous, a pumping system upgrade project, which was designed and constructed independently, will work alongside the storm surge barrier to help minimize freshwater flooding in the city.

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Using Advocacy to Enhance Gulf Coast Resilience

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Project Summary

The Gulf Restoration Network is an environmental advocacy organization that seeks to unite Gulf Coast citizens to protect and restore natural resources. Through empowering local communities, taking legal action against industries that have degraded Gulf Coast and community resiliency, and monitoring government action to ensure sustainable management of contemporary natural resources, the Gulf Restoration Network is helping restore and maintain the natural systems that both define and protect Gulf Coast communities.

Project Background

The Gulf Coast of the United States is incredibly vulnerable to climate change impacts. Low-lying topography makes the region sensitive to sea level rise and increasing storm surge, challenges that are exacerbated by regional land use patterns and industry practices. For example, oil and gas extraction activities in the region have destroyed many natural wetlands, reducing coastal flood protection. In addition, regional water quality is threatened by pollution runoff, which may vary with shifting rainfall and flow patterns in the future, affecting both drinking water quality and the health of Gulf Coast ecosystems.

The Gulf Restoration Network is an environmental advocacy organization that is working in a variety of arenas to address regional vulnerabilities, enhance climate resilience, empower citizen advocacy, and promote the responsible management of the Gulf's natural resources both now and in the future. The Gulf Restoration Network has been actively working along the Gulf Coast for 20 years, and works primarily in Mississippi, Louisiana, Alabama, Florida, and Texas, as well as with upland watershed partners along the Mississippi River Corridor.

Project Implementation

The Gulf Restoration Network (GRN) has two major initiatives designed to improve the resilience of Gulf Coast ecosystems and communities. The Natural Defenses Initiative and the Healthy Wetlands Initiative are helping regional communities restore natural features to enhance storm protection and resilience. A large part of these initiatives focuses on corporate accountability, demanding that corporate activities that have increased community vulnerability to climate change impacts be rectified. For example, GRN is ensuring that fines from the BP Deepwater Horizon oil spill are used for coastal restoration projects that enhance resilience. GRN also works directly with communities impacted by unsustainable corporate and governmental practices, and has helped file several lawsuits to hold companies accountable for resilience losses. GRN also monitors water discharge permits issued by the state to ensure they fall within the Clean Water Act guidelines. Similarly, GRN monitors wetland permits issued by the state and USACE and associated activity to make sure all activities that impinge on wetlands are permitted and mitigated so that the region experiences no net loss of wetlands. Maintaining and restoring natural wetlands helps enhance coastal resilience, and monitoring water pollution help maintain the integrity of critical regional water resources.

In a separate effort known as the Healthy Waters Initiative, the Gulf Restoration Network is working to ensure that federal and state governments in the Mississippi River Basin reduce pollutant contributions to the Gulf of Mexico. This group, known as the Mississippi River Collaborative, is attempting to reduce upstream pollutants in the basin to reduce the size of the Gulf of Mexico Dead Zone. The Dead Zone fluctuates in size depending on rainfall and flow regimes, with periods of high precipitation and streamflow delivering higher levels of nutrients to the gulf. With an uncertain precipitation future, reducing pollutant loads can help mitigate potential increases in the size of the Dead Zone.

The Gulf Restoration Network is also working with regional partners to increase community-based adaptation efforts. The nonprofit is encouraging communities and state agencies to develop climate adaptation plans, and joined forces with the Gulf of Mexico Alliance in 2008 to establish a regional plan for climate change adaptation. The Gulf Restoration Network has also supported regional adaptation efforts, including the development of the Greater New Orleans Urban Water Plan.

In almost all of their work, the Gulf Restoration Network utilizes partnerships, expert input, regional data, and technology. Partnerships bring local and national support to different advocacy campaigns, and also help increase public education and outreach. Expert input, particularly legal advice, is critical for ensuring the success of advocacy efforts and for taking legal action to help enhance resilience. Published data, particularly scientific information, is also used to support advocacy efforts and inform local adaptation campaigns. Technology has also been critical to accomplishing various projects; for example, GRN uses digital platforms to communicate with the public.

Project Outcomes and Conclusions

Through advocacy, community engagement, and policy monitoring and reform, the Gulf Restoration Network and its partners have effectively been protecting and enhancing regional communities, wetlands, and water bodies along the U.S. Gulf Coast. Accomplishments range from finalizing the BP settlement, which will provide $18.7 billion for Gulf Coast restoration, to prohibiting the construction of dams, oil pipelines, and other projects that would undermine ecological and community resilience, and working with local communities to prevent harmful industrial and/or infrastructure developments. The Gulf Restoration Network has also developed a series of digital resources for planning agencies and the public, all of which are available in their online library. Resources include a wetlands protection guide, various regional report cards on water quality and wetlands restoration, and a natural infrastructure discussion paper.

Moving into the future, the Gulf Restoration Network hopes to continue its current initiatives and be adaptive, addressing any new challenges that may arise and threaten the integrity and resilience of natural and human communities in the Gulf Region. GRN continually evaluates its success by looking at large-scale metrics related to policy change, community engagement levels, and effective resource protection and restoration, including acreage of natural areas protected and money allocated from federal and state agencies to fund regional restoration. Although GRN faces strong opposition from regional industries (e.g., oil and gas), and must compete for financial resources with other groups, it believes that as climate change continues to impact the region, communities, municipalities and the state government will increase their engagement in adaptation and restoration efforts.

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Waveland's Climate-Informed Local Hazard Mitigation Plan Update

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Project Background

Waveland, Mississippi, is a small town located along the Mississippi Sound of the Gulf of Mexico. A majority of the municipality is less than 15 feet above sea level, and 90% of the municipal area is in a special flood hazard zone. Any event larger than a base flood (i.e. a flood with a one percent chance of being equaled or exceeded in any given year, also known as a 100-year flood), including rainfall-related flooding and storm-surge flooding, leads to neighborhood damage, and frequent floods are affecting home mortgages and flood insurance rates. Recurrent flooding is driving many residents out of the area, as they cannot afford to pay the increasing cost of flood insurance and keep up with repairs associated with flood damage. Waveland's population has shrunk significantly since Hurricane Katrina.

In response to increasing flood risk and community vulnerability, the City of Waveland decided to update its 2007 FEMA-approved hazard mitigation plan in order to better mitigate the risks of flood and other natural disasters, hoping that enhanced community safety would reduce resident migration. Updating the hazard mitigation plan would also maintain the city's eligibility for federal disaster assistance, and earn the municipality credits under the National Flood Insurance Program (NFIP) Community Rating System (CRS), helping reduce insurance rates for homeowners and business owners. The hazard mitigation plan update process was funded by a FEMA grant, and grant funds were matched by an in-kind grant from an outside party. Waveland also received a $34,000 grant from the Mississippi-Alabama Sea Grant Consortium to incorporate sea level rise and other climate change impacts into its plan update. Specifically, this grant allowed the city to hire a consulting firm with climate change experience to lead an analysis of how climate change may impact the city, and to link climate change with hazards identified in the hazard mitigation plan.

Project Implementation

The hazard mitigation plan update process began in Fall 2012. Waveland hired AMEC Environment and Infrastructure (AMEC) to facilitate the plan update process and to help incorporate climate change impacts into the plan revision. Multiple local government and agency representatives were also engaged throughout the process via a Hazard Mitigation Planning Committee, which the city was required to form under the Disaster Mitigation Act (DMA) planning regulations. The plan revision process followed DMA requirements and featured integration of FEMA CRS and Flood Mitigation Assistance Program (FMAP) planning principals, resulting in four phases: organize resources, assess risks, develop the mitigation plan, and implement the plan and monitor progress As a result, the planning process satisfied the requirements of six federal programs: FEMA's Hazard Mitigation Program, Pre-Disaster Mitigation Program, the Community Rating System, Flood Mitigation Assistance Program, and Severe Repetitive Loss Program, and the USACE flood control project criteria.

Phase 1, Organize Resources, involved setting up a process for the plan update, organizing the Hazard Mitigation Planning Committee, and engaging the public. The city passed a resolution forming the Hazard Mitigation Planning Committee and approving the established planning process, which was developed by AMEC, the fire department, and other city officials. To engage the public and other critical stakeholders, the city held a series of private and public meetings discussing the plan process and requesting feedback. For example, at the project kick-off meeting, members of the public provided input on how they would like to be involved in the process, and identified preferred methods of communication; they were then able to attend subsequent meetings and provide input on the draft report. Significant stakeholders, including county, state, and federal agencies and nearby municipalities, were also engaged to participate in meetings and different stages of the plan update. Community planning and hazard mitigation planning efforts among these different agencies and groups were also identified to ensure they would be integrated into Waveland's final plan revision.

Phase 2 involved conducting a risk assessment to better understand the various hazards threating the City of Waveland. This phase consisted of identifying potential hazards, gathering available information and modeling on each hazard, conducting a vulnerability assessment to understand future risk, and assessing the city's capacity to implement hazard mitigation activities. To facilitate this process, AMEC distributed worksheets to the Hazard Mitigation Planning Committee and other regional stakeholders to gather information on past and current hazards, existing city capabilities and values, and to identify potential response actions. Via another worksheet, AMEC also evaluated progress on mitigation activities identified in the 2007 hazard mitigation plan. Worksheet information and input from HPMC meetings were used to identify known and potential major hazards, nine of which were not assessed in the previous hazard mitigation plan, including climate change (sea level rise and storm surge), flooding, and drought.

Once these hazards were identified, AMEC searched the scientific literature and available agency databases, and used a variety of available tools and GIS to gather relevant information, including past occurrences and future projected trends. This information was overlaid with city data (e.g., housing distribution, facility locations, cultural, historic, and natural resources locations, population trends, land use) to model future vulnerability, which for each factor was ranked on a scale from Extremely Low to Extremely High. Finally, AMEC conducted a capacity assessment, evaluating the various plans, ordinances, and partnerships available to the city that could be used to implement hazard mitigation activities.

Climate change was explicitly incorporated as a hazard for the City of Waveland, but plan authors also identified how climate change may interact with other hazards, such as coastal bank erosion and dam and levee failure. Climate information and projections for the report were sourced from a variety of peer-reviewed state and federal reports. AMEC also used several available climate tools to incorporate site-specific projections and help visualize potential climate impacts on city resources. For example, it utilized the NOAA Sea Level Rise Viewer to model sea level rise of 1 foot (best case), 3 feet (average case), and 6 feet (worst case), overlaying these projections with GIS files of city infrastructure. The Sea Level Rise Viewer was also used to visualize how storm surge may change with different sea level rise scenarios. In addition, AMEC utilized the National Weather Service's Sea, Lake and Overland Surges from Hurricanes (SLOSH) model to calculate potential storm surge associated with hurricanes in the absence of sea level rise. AMEC also used the U.S. Drought Monitor to demonstrate drought trends in the city and broader region and obtained flood and hazard information from Digital Flood Insurance Maps and Flood Insurance Rates Maps.

After identifying future hazard risk, Phase 3 focused on developing the updated mitigation plan. A series of meetings with the HPMC was used to review and update the major goals of the mitigation plan, as well as identify and analyze potential mitigation actions to address key hazards. Only hazards deemed to be high risk during the risk assessment stage were considered for action development, including: climate change (storm surge/sea level rise), coastal/canal bank erosion, floods (100/500 year floods and localized flooding), hurricanes/tropical storms/storm surge, thunderstorms, and hazardous material release from railroads. The draft plan was circulated for comment, and the final version was published and adopted by the city in 2013.

Project Outcomes and Conclusions

In general, by identifying key hazards and future risk, Waveland's local hazard mitigation plan will facilitate risk-based decision-making to mitigate city vulnerability to both climate and non-climate hazards. The Waveland community has been very receptive to the plan revision process and different component projects. The final plan is posted on the city's website and on social media, allowing residents to have open access. Since plan publication in 2013, the City of Waveland has begun to implement priority projects and actions to mitigate municipal risk. For example, the city is identifying the most flood-prone zones, and since 90% of the city lies in a special flood hazard area, the city is implementing a $6.9 million drainage project aimed at improving floodwater drainage. While initial steps toward risk mitigation are promising, city officials anticipate that limits on staff capacity and funding will be among the major barriers to implementing key actions identified in the plan.

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Resilient Water Supply Planning at Orange Water and Sewer Authority, North Carolina

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Project Summary

The Carrboro-Chapel Hill region of North Carolina has experienced several severe droughts, is experiencing steady population and economic growth, and may also experience increased flooding and more severe droughts as a result of climate change. As a critical water, wastewater, and reclaimed water services provider for this area, Orange Water and Sewer Authority is preparing for an uncertain water supply future through a variety of methods. Orange Water and Sewer Authority is attempting to increase the resilience, reliability, and redundancy of its water sources, operations, and facilities, with steps such as diversifying its water supply portfolio, increasing water conservation pricing signals and water conservation education and outreach, upgrading and building new facilities to reduce water use, and working with neighboring utilities to enhance the region's water supply planning efforts and modeling climate impacts on those supplies.

Project Background

Orange Water and Sewer Authority (OWASA) supplies drinking water, wastewater, and reclaimed water services to the Carrboro-Chapel Hill region of North Carolina. North Carolina is fortunate to have ample water supply in most years, but it also occasionally experiences severe droughts. The region experienced two historic droughts in 2001-02 and 2007-08, and OWASA and many surrounding water utilities in the region found it necessary to implement mandatory water use restrictions to extend their available supplies. The two extreme droughts heightened utility and customer awareness about the importance of planning for unpredictable futures, as running out of water is not an option. In addition, the utility is concerned about the potential for extreme flood events, which are projected to accompany increasing climate variability.

To ensure stable water supply and system operation under a range of uncertainty, OWASA has been engaged in a continual movement toward climate preparedness since the late 1990s. Although many of the utility's operational changes have helped enhance climate resiliency, more formal efforts regarding climate preparedness have emerged over time, particularly as climate science has improved and in the wake of the recent severe droughts in the region.

OWASA funds its ongoing operations and maintenance programs solely from the revenues it receives from its water, sewer, and reclaimed water customers. It has authority to debt finance capital improvements, and occasionally receives project funding in the form of federal and state grants and partner funding. For example, design and construction of OWASA's reclaimed water system was funded by state and federal grants totaling about $2.25 million and by The University of North Carolina at Chapel Hill, which provided about $13 million for the project.

Project Implementation

OWASA's first major step toward resilient water management included an effort to increase water supply capacity and diversify long-term water supply sources by acquiring an active local rock quarry for future use as a water supply reservoir. In accordance with OWASA's agreement with the quarry operator, quarrying will cease in 2030, at which time OWASA will be able to fill the quarry pit and use it as a water storage reservoir. Purchase of this quarry provides long-term reliability in water supply by enhancing local water storage capacity and generating a water storage area that is locally managed. This no-regrets action (i.e. an action that provides benefits irrespective of climate change) also has financial benefits in the short term, as OWASA receives annual lease payments (revenue) from the company that mines the rock from the quarry. OWASA projects that at the conclusion of mining, the Quarry Reservoir will provide between 1.3 and 1.9 billion gallons of additional water storage capacity.

In 2001-2002, North Carolina experienced one of the most severe droughts on record. OWASA implemented mandatory water use restrictions and was able to meet essential water needs throughout that event, but the utility became acutely aware of the community's vulnerability to subsequent and/or more severe droughts. Over the next several years, OWASA implemented a variety of projects to increase water conservation, reduce water demand, and increase water reuse and recycling. The agency began recycling process water at its drinking water plant, which reduced average day raw water withdrawals by about 6-7%. It also implemented various new pricing mechanisms, including seasonal water pricing (applicable to all nonresidential customers and master-metered residential developments) and increasing block water rates for individually metered residential customers to encourage conservation, especially during the peak summer season. In partnership with UNC Chapel Hill and with additional financing from federal and state grants, OWASA also designed, constructed and launched a reclaimed water system, which began operations in 2009. The reclaimed water system now meets about 10% of the community's total water demand, and it reduces long-term water costs for the University.

The reclaimed water storage tank and pump station is designed to be resilient to climate-change impacts. During the design and construction process, OWASA and partners knew that the plant needed to be elevated, at minimum, to withstand a 100-year flood event. However, given recognition of increasing climatic variability and the potential for increased flood volumes, they elected to elevate the plant even higher in order to enhance its long-term resilience. By building climate resilience into the design and construction phases of their already funded project, OWASA implemented a low-cost adaptation strategy that will help maintain water supply resilience and reliability under a variety of future climate conditions.

In 2014, as part of its strategy to maintain a diverse portfolio of water supply options, OWASA applied to the State of North Carolina to retain the right to use a portion of the water supply storage available from Jordan Lake, a federally constructed multipurpose reservoir located south of the OWASA service area. OWASA now holds a 5% water storage allocation, and can access that Jordan Lake water by having a nearby utility withdraw, treat and deliver water to OWASA through water mains interconnections with a third utility. This arrangement is for emergency access purposes only, and does not ensure OWASA access to its water allocation when needed and in the amounts needed. OWASA has been partnering with neighboring utilities to evaluate the most cost-effective options for ensuring permanent access to the water supply available in Jordan Lake. Jordan Lake has proven to be resilient to the recent extreme regional droughts; therefore, OWASA believes that by retaining access to that reservoir, it will further reduce its vulnerability to future droughts.

Since 2007, OWASA has also been engaged in a variety of efforts to more specifically evaluate how climate change may affect its water supply. For example, the 2010 update of the utility's Long Range Water Supply Plan includes water yield estimates that are generated from historical data that include water supply trends during historic droughts of record. OWASA also developed a "what if" water shortage scenario to evaluate how climatically driven water shortages could affect its water supply. In the scenario developed for the Long Range Water Supply Plan, OWASA assumed historic reservoir inflows would be reduced by 30%, and it examined what the impacts would be on water supply yield and evaluated how strategies and actions identified in its plan could be used to ensure an adequate water supply even given potential shortages associated with that scenario.

OWASA is now engaged in more formal climate and water supply modeling. Through a Carolinas Integrated Sciences and Assessment partnership, a PhD student at the University of South Carolina is doing research that will help OWASA apply current climate science in its water supply planning and decision-making processes. The student will use output from several downscaled climate change models as input into a hydrologic model of the OWASA system, and the results will be used to assess the resiliency of alternative water supply development scenarios. Through downscaling and comparing the results of different climate models, OWASA hopes to have a better understanding of how increasing climate variability may affect the yield and reliability of its water supply system over the long term. Although the models will not be used to predict future levels of risk, they will be used to help OWASA better understand under what climate scenarios it will not be able to support current and projected water demands. OWASA plans to identify management solutions that address these challenges and maintain reliable water supply across various scenarios, thereby building resilience into its future water management framework. These projections will also likely be incorporated into revised demand and yield projections through 2065, thereby informing the actions and investments that the utility makes in the years ahead.

OWASA operates under the general philosophy that no matter what the climate future, everyone will be better off with more efficient use of current water supply. To that end, the agency has simultaneously engaged in a variety of activities to enhance conservation and the overall reliability of its water services, including: increasing efficiency at various facilities, developing a drought response operation protocol and Water Shortage Response Plan, developing a comprehensive emergency management plan, investing in standby power generators at all critical water and wastewater facilities, and engaging in significant public outreach and education. OWASA is also engaged in climate mitigation activities, and is taking steps toward reducing its operational carbon footprint.

Project Outcomes and Conclusions

OWASA's efforts to promote the conservation and sustainable management of the community's water resources have been very successful. Efforts to recycle processed water at its drinking water facility reduced overall water withdrawals by 6-7%, and the reclaimed water system developed in 2009 now meets about 10% of the community's total water demand. As a result of those and other efforts, annual average-day drinking water demands remain at about the same rate as in 1991-92, despite about a 60% increase in customer accounts. OWASA credits this success to a combination of operational changes and upgrades, greater conservation pricing levels, and extensive public education and outreach. OWASA continues to closely monitor water demand and supply, and is also looking for climate resilience metrics to incorporate into its monitoring framework.

Moving into the future, OWASA hopes to continue to build greater resilience, redundancy, and reliability into its operations and facilities in order to maintain a sustainable water supply in the face of an uncertain future. The redundancy of local water supply sources will expand as the quarry transitions to a water storage reservoir starting in 2030. OWASA is also exploring opportunities to gain more permanent access to a portion of the water supply available from Jordan Lake, a federally constructed reservoir that serves as a regional water supply source. Water utilities must apply to the State of North Carolina to receive water storage allocations from this lake, and OWASA currently has a 5% (5 million gallons per day) allocation. However, OWASA does not have a permanent way to access this water, aside from purchasing drinking water (that originates from Jordan Lake) from another utility. In the short term, this provides an insurance policy against running out of water during prolonged drought, but OWASA is searching for a more permanent, sustainable solution that successfully overcomes the sociopolitical and economic hurdles associated with the use of water from Jordan Lake.

Although OWASA recognizes the importance of integrating climate science with water supply planning, it has been somewhat limited by the lack of actionable science. For example, past climate-water yield analyses have been impeded by a lack of usable downscaled climate modeling data at temporal and spatial scales needed to inform for water supply planning and decision-making. However, OWASA has not let this challenge stop its efforts to enhance climate resilience. For example, to simulate water shortages in developing a long-range water supply plan, OWASA developed a simple water reduction scenario — what if reservoir inflows declined by 30 percent? This approach may lack the finer detail available with climatic modeling, but it still provided the utility with a hypothetical water shortage scenario with which to test its management policies and the potential reliability of alternative water supply investment scenarios. OWASA is now working with university partners to use downscaled climate models to inform its plans. Looking to the future, the utility is also interested in partnering on similar studies into how increasing climate variability may affect future drinking water quality and water use patterns and demands.

Much of OWASA's success stems from strong partnerships and stakeholder support. Partnerships with regional universities, participation in the Jordan Lake Regional Water Supply Partnership, and direct representation on the EPA's Climate-Ready Water Utilities Working Group have helped OWASA to better understand available science and adaptation options, as well as explore regional opportunities for collaboration. Strong stakeholder support and financing has also laid the foundation for many of OWASA's largest projects, including development of the reclaimed water system in 2009. OWASA hopes to expand its partnership network with other utilities in the future in order to reduce cumulative risk and leverage opportunities to maintain a reliable and resilient water supply for the entire region.

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Long-Range Water Supply Planning in the Town of Cary, North Carolina

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Project Summary

The Town of Cary, North Carolina, recently completed an update to its Long-Range Water Resources Plan. The plan update incorporates a probability-based look at how various factors influence water supply, such as population growth and climate variability. The plan update also identifies priority strategies and includes an implementation plan to ensure resilient and sustainable water management through 2060.

Project Background

The Town of Cary provides water, stormwater, and wastewater services to approximately 152,000 residents located in the Triangle Region of North Carolina. Cary has been involved in long-term water resources planning since 2000, in order to maintain high-quality water supply service for the Town's residents and businesses in the future, and to do so in a financially and environmentally responsible way. Although this region typically has an abundance of water, two droughts of record have occurred in the recent past, and the Town recognizes that variability in factors such as customer demand, land use, and climate (including drought, temperature increases, and extreme weather events) could affect water supply if not planned for accordingly. In addition, expected population growth in the region underscores the importance of water supply planning for the future.

The Town of Cary developed and published its Long Range Water Resources Plan in 2013. The Plan builds off of previous plans published in 2000 and 2007, and addresses the continuation of the Town's water conservation and reclaimed water use programs. The Plan complements other Town efforts to enhance stormwater management, protect open space, and utilize green infrastructure to improve and maintain flood and water quality protection. Funding for the Long Range Water Resources Plan came from each of the areas for which the plan was developed, including the Town of Cary and the Town of Morrisville, the Town of Apex, and Wake County/Research Triangle Park. The Town of Cary, which provides water services to the Town of Morrisville, funded plan development using utility capital revenue sources. Total expenditures for plan development were $584,300 for the Town of Cary and $116,850 for the Town of Apex. Expenditures incurred by Research Triangle Park were not available at time of publication.

Project Implementation

Building off of previous water planning efforts, the 2013 Long Range Water Resources Plan (LRWRP) followed a very comprehensive process and integrated a variety of information to ensure resilient and sustainable water management for the Town of Cary. Initially, the planning team conducted surveys of other national water resource managers with advanced water resources programs and/or sustainable and diverse water resources portfolios. Information gathered from interviews was used to validate and inspire strategies and resources developed during the planning process. One interesting finding from these surveys was that, at the time, few utilities had accounted for climate variability, although integration of this type of information in water supply planning is increasing.

The planning team then conducted a series of four workshops with municipal and county staff and a consulting senior advisory panel. The purpose of these workshops was to (1) facilitate conversations about critical components to consider during the plan update, (2) develop a decision framework to guide decision-making during the planning process, (3) clarify the overall goal of the plan update, identify core values, and outline criteria and objectives critical for achieving plan success, and (4) screen a list of potential water resource strategies gathered from previous workshops, interviews, local expert knowledge and experience, and additional research to identify those strategies most likely to fit the needs of the LRWRP. This final stage resulted in a shortlist of 22 strategies that the planning team carried forward through the planning process.

The Plan integrated a variety of new information. A series of directed technical evaluations were completed, including a review of regional water supply and resource recovery potential, service level reviews, and system reliability analyses. Resultant white papers from these studies were referenced throughout the plan update process. The 2013 LRWRP included several components related to climate variability, including an analysis of historic water demand (which includes data gathered during past drought periods), a climate-informed water demand forecast, and the consideration of climate variability, amongst other drivers, in a scenario planning exercise.

Understanding historic water demand was a critical component in analyzing potential future changes and developing management strategies. The Town of Cary analyzed historic daily and annual average daily demand, finding distinct seasonal differences. These analyses also showed that water supply and demand can shift drastically in response to drought periods, as it did during several years of record drought (2002, 2007-08), as well as during extremely wet periods. By including drought years in its analysis of historic water demand, the planning team effectively incorporated water shortage supply planning into its Plan.

The Plan included a water demand forecast, which analyzes demand through 2060 based on current municipal programs and policies and through incorporation of uncertainty. Key uncertainty factors integrated into this forecast included: population growth rate, weather-induced annual variability in water use, amount of processed water used in water treatment, amount of non-revenue water, and maximum day peaking factors (which compares water usage on the highest use day of the year with the annual average). This forecast was generated using a Monte Carlo simulation, which helps evaluate the magnitude and likelihood of different combinations of demand scenarios. By including variables influenced by weather and local climate, as well as by using a simulation that helps illustrate uncertainty and variability in demand forecasts, the Town of Cary was able to generate a water demand forecast that incorporates a very basic assessment of how climate may interact with other factors to influence future water demand.

Management strategies identified throughout this planning process were screened through a scenario planning exercise. Climate variability, namely the potential for increased extreme events and associated costs, was one component analyzed in this exercise, along with different economic/business, technology, and societal/political scenarios. Participants determined that increasing climate variability would likely lead to shifts in water supply and pricing, in turn creating more aware and educated consumers who acknowledge and respect water as a finite resource and who adjust their consumption behavior based on this understanding. Based on these variable future scenarios, the planning team added several strategies to its previously established shortlist to enhance the overall resilience of its final Plan.

All strategies identified and developed through the planning process were then prioritized and grouped, culminating in five resultant key strategies dealing largely with water supply, land use and master planning, and increasing best management practices.
The five strategies include:

- Increase water supply via Jordan Lake allocation
- Increase water supply and/or storage by other means (i.e. Crabtree Creek, Cape Fear River, Kerr Lake)
- Increase water supply and/or storage via interconnections (e.g., implementing long-term water purchase agreements with other utilities in the region)
- Implement integrated master planning and strategic utility resource utilization (i.e. integrate community planning, water resources management, utility planning, and sustainable development)
- Promote best management practices (e.g., optimize internal operations, manage customer demands for improved efficiency, utilize reclaimed water)

These strategies were then translated into a water resources portfolio, which outlines a collection of potential strategies than can be used to meet outlined goals and to address challenges identified though water forecasting and scenario planning. The final Plan outlines actions to be taken through 2060, and includes an implementation plan, which calls for expanded water treatment and supply sources by 2023 and 2032, respectively.

Project Outcomes and Conclusions

In developing the LRWRP, the Town was both hindered and assisted by available data. Downscaled climate models were used to explore possible future conditions, but results from these models were highly inconsistent and provided little guidance at the smaller spatial scales required for municipal planning. Similarly, the planning team recognized the lack of local specificity in current precipitation data. In the face of these data gaps, the planning team chose to plan for variability in order to ensure resilience, acknowledging that projections and associated management responses can be adjusted as more refined models and data become available. Comparatively, other readily available data – including stream gauges, drought indicator wells, and lake inflow data – has helped the utility better understand and plan for future water supply and shortage periods.

The Town published the Long Range Water Resources Plan in 2013. Since publication, the Town of Cary has moved forward with implementing various strategies and actions. Implementation of the suite of actions identified through this process will help the Town of Cary maintain stable water supply into the future and enhance the overall resilience of the Town's water resources. For example, the Town of Cary is promoting interconnections with other water system suppliers in the Jordan Lake Water Supply Partnership. Diversification of water supply sources enhances supply reliability and provides redundancy during extreme events such as droughts. Cary is also engaging in customer education and outreach surrounding water use efficiency, because the town believes having an educated and aware consumer base will increase public responsiveness and the effectiveness of conservation measures during drought or other water shortage periods. In addition, Cary developed a Water Shortage Response Plan to be activated during periods of acute or chronic water shortage. This plan includes a hydrologic modeling demonstration, demonstrating that in a severe water shortage scenario (i.e. where reservoir inflows to its main water source, Jordan Lake, were decreased by 36% on a daily basis over the 74-year period of record in the model), implementing its water shortage response plan would allow the Town to preserve 50 days of its available water supply under projected 2030 demands. By comparison, if the same conditions occurred and the Town had no water shortage plan in place, consumers would use up all available water, resulting in a water crisis. The Town is also monitoring its ability to supply water to customers, and looking specifically at how interconnections with other water systems can be used to supplement Cary's water supply in case of a local system failure. These actions, along with others presented in the LRWRP portfolio, will be reevaluated in five years, ensuring that the Town of Cary has a water supply plan that reflects the most current conditions.

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Upper Neuse Clean Water Initiative: Collaborative Land Protection to Maintain Water Quality

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Project Summary

The Upper Neuse Clean Water Initiative (UNCWI) is a collaborative effort between regional land trusts, nonprofit entities, and several local municipalities and counties to protect drinking water supplies and quality in the Upper Neuse River Basin through land acquisition and/or conservation easements. A collaboratively developed Conservation Plan guides land acquisition by prioritizing land parcels according to their importance to water quality and their ability to provide other conservation benefits for the basin. Since original plan development, UNCWI partners have successfully protected 7,658 acres and 84 stream miles, with benefits for water quality, wildlife, human communities, and overall landscape resilience.

Project Background

The Upper Neuse Basin in the Piedmont region of North Carolina covers 770 square miles and contains nine reservoirs that provide drinking water to more than 600,000 people in six different counties. Population growth and increasing development, which are projected to continue at minimum through mid-century, are threatening basin-wide water quality by converting natural land cover to impervious surfaces. Higher impervious cover increases runoff and pollutants entering regional waterways and reduces infiltration, patterns that could be exacerbated by increasing precipitation variability and rainfall intensity. In general, development also impacts wildlife habitat connectivity, carbon sequestration, and other critical ecosystem services. In light of projected population growth and increasing climatic variability, stakeholders throughout the basin recognize the importance of protecting current water quality and supply to meet future demand.

The Upper Neuse Clean Water Initiative, a partnership of land trusts, the city of Raleigh, and other local governments, are working together to identify and voluntarily protect lands critical for maintaining the region’s water quality into the future. UNCWI works with local landowners to purchase land or establish conservation easements to reduce development in critical areas and maintain water quality. The Conservation Trust for North Carolina coordinates this initiative, and other members include the Ellerbe Creek Watershed Association, Eno River Association, Triangle Greenways Council, Triangle Land Conservancy, Tar River Land Conservancy, and The Conservation Fund. The city of Raleigh established the initiative, and many local municipalities have been critical partners, including Durham, Orange, and Granville counties, and the cities of Durham, Hillsboro, Butner, and Creedmoor.

Funding for activities of the Upper Neuse Clean Water Initiative comes from a variety of sources. Raleigh created a dedicated revenue source for the program in 2011 by enacting a small monthly “watershed protection fee” for water customers based on monthly water use, which helps fund UNCWI’s conservation easements and land purchases. Raleigh has contributed over $5.8 million since 2005 to buy land and conservation easements, and to support land stewardship projects to maintain water quality. In 2010, UNCWI received a grant from the U.S. Endowment for Forestry and Communities and the Natural Resources Conservation Service to work with local forest owners to develop forest stewardship plans and create conservation easements on their property. The North Carolina Clean Water Management Trust Fund, Durham, Orange County, Granville County, and Creedmoor have also contributed money to help purchase and protect land.

Project Implementation

In 2005, the Upper Neuse Clean Water Initiative developed a Conservation Plan to guide land protection activities undertaken by all partners. The plan identifies water quality and supply issues facing the Upper Neuse Basin, discusses local and regional regulatory frameworks impacting land conservation and water quality regulation, and describes potential funding streams (local, state, federal) to fund land protection. The Plan also describes a collaborative effort that mapped, modeled, and prioritized the most critical lands for protection within the basin.

This process, led by the Triangle J Council of Governments and The Trust for Public Land (TPL), utilized public meetings, a technical advisory team (TAT) comprised of water resources experts, and GIS mapping to identify conservation priorities and critical lands for protection within the basin. Community members identified protecting water quality as the primary conservation priority, in addition to protecting working lands and maintaining aquatic and terrestrial habitat connectivity. The TAT identified data layers that influence water quality, such as slope, soil type, impervious surface cover, and current land use, and input these factors into the TPL Greenprint Framework, a GIS model. The Framework analyzed and categorized different land parcels within the region based on their ability to help maintain water quality. Parcels identified as having the highest benefit to water quality were then overlaid with parcels providing other conservation value to community members, including parcels containing working lands, wetlands, and areas with special biodiversity significance as defined by the North Carolina Natural Heritage Program. Parcels providing the most benefits for protecting water quality while simultaneously providing other community conservation priorities were flagged as high priority parcels for conservation. (More information on the process used to identify and prioritize lands can be found in the Conservation Plan.)

In total, the model identified 24,000 unprotected acres in the Upper Neuse Basin as high priority for future protective action. Since parcel boundaries were not explicit in the model, local land trusts developed additional criteria to identify parcels of greatest conservation priority based on their ability to maintain water quality. Criteria included length of stream frontage, adjacency to protected land and/or a significant natural heritage area/element occurrence, and parcel size.

The Upper Neuse Clean Water Initiative has used several other tools in its effort to protect water quality. The University of North Carolina Environmental Finance Center conducted a "revenueshed" analysis to identify watershed locations that could be used to generate revenue for water quality protection. This analysis provided the foundation for Raleigh's Watershed Protection Fee for municipal customers, which funds current land acquisition by UNCWI partners. Duke University also created a water quality benefits estimation tool specific to the Upper Neuse Basin. This tool analyzes property characteristics, including location, development risk, and development type (agricultural, forestry, urban) to model estimated water quality benefits by preventing development. In essence, the tool models what is being prevented (e.g., enhanced nitrogen runoff) due to land protection efforts. This has been a useful measurement and communication tool; UNCWI can roughly track the amount of nitrogen, phosphorous, and sediment being kept out of regional water through land conservation.

Formal public outreach as a part of this project has largely been focused on landowners. However, local land trusts lead public awareness events, many municipalities are engaged in community education and outreach, and multiple groups within the basin are working to enhance public understanding of the land-water connection to build support for conservation and fundraising efforts.

Project Outcomes and Conclusions

Over the 10 years since the Conservation Plan was published, UNCWI partners have protected 88 properties through purchases or conservation easements, protecting a total of 7,568 acres and 84 stream miles. The total value of this land is well over $72 million. These protected acreages help maintain water quality and quantity by slowing and filtering precipitation and runoff, and will continue to play a critical role in drinking water provisioning for municipalities in light of projected population growth and climate variability. In addition, UNCWI partners completed a Forestry Conservation Plan in 2010 through a grant from the US Endowment for Forestry and Communities to engage private forest landowners in best management practices to maintain water quality.

The collaborative nature of the UNCWI has facilitated overall success, with participants leveraging their expertise and sphere of influence to assist the land protection process. For example, local land trusts interface with landowners to negotiate purchases/easements, while governments provide project funding. The Conservation Trust for North Carolina acts as intermediary between governments and land trusts to keep communication pathways clear. Compartmentalizing roles this way provides efficiencies, utilizes the expertise of each participant, and builds upon the trust that regional citizens have with their local land trust to responsibly manage land. This last component is particularly important to foster and maintain, as the loss of North Carolina's state tax credit for land donation leaves less incentive for landowners to donate or sell their land, although the federal income tax deduction and reduced property and estate tax incentives still apply.

Some of the major challenges encountered in the UNCWI's land protection efforts include politics and funding. With so many counties and cities drawing water from the basin, and following a EPA 303-D Impaired Water listing of Falls Lake, a major reservoir, there was some tension between upstream municipalities being required to address water quality via a state mandate and those counties downstream advocating for additional voluntary land protection financing via the UNCWI partnership. Land trusts have been key players in mediating relationships between these regulated and non-regulated municipalities to further land protection efforts while meeting state water quality regulations for Falls Lake. In terms of funding, having a partnership of local governments and nonprofits opens up opportunities for collaborative grant funding that would be unavailable to each of these groups working in isolation.

In 2015, UNCWI partners updated their Conservation Plan. The new plan outlines land protection and conservation priorities through 2045 based on a GIS-based Watershed Protection Model that incorporates updated land cover information, the new best available scientific knowledge, and refined stakeholder objectives and protection prioritization criteria. With this plan, funding from the city of Raleigh, and the participation of willing landowners, the UNCWI hopes to protect an additional 30,000 acres of land over the next 30 years to continue protecting drinking water sources. In addition to updating the Conservation Plan and protecting additional acreage, the UNCWI hopes to maintain positive relationships and open communication between partners and funders, and ensure that green infrastructure and natural area benefits are considered in regional planning efforts. The UNCWI also hopes to expand its work on forest and agricultural best management practices, and increase public education and outreach.

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Integrating Climate Change into Plan Revisions at Francis Marion National Forest

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Project Summary

In 2012, the USFS released a Planning Rule requiring the integration of climate change impacts, vulnerability, and adaptation into revisions of forest management plans. Between 2012 and 2016, the Francis Marion National Forest undertook the forest plan revision process, relying on the evaluation of changes that have occurred since 1996 as well as outcomes from public meetings and other outreach efforts. The initial revision was released in August 2016 and the final revised forest plan is effective as of May 2017.

Project Background

Every national forest is guided by a land and resource management plan (commonly known as a forest plan) – a document that sets forth guiding management principles on a 10-15 year time horizon. Since 2012, the Francis Marion National Forest in coastal South Carolina has been undergoing a forest plan revision, and its revised plan is incorporating climate change considerations and promoting hydrological restoration. The 1996 Francis Marion Forest Plan focused largely on helping the forest recover from hurricane impacts, while the revised forest plan shifts management emphasis to ecological restoration of longleaf pine and isolated wetland ecosystems and using restoration to contribute to the economic and social sustainability of the region. Wetland restoration will benefit wildlife habitat, as well as help capture and hold stormwater, increasing flood protection for adjacent communities and helping recharge groundwater. In addition, restoring the natural hydrology of the forest's wetlands may help mitigate some of the salinization occurring in nearby coastal communities, many of which are experiencing saltwater intrusion into drinking water wells.

Project Implementation

In developing the plan, the forest engaged in several public outreach efforts between October 2012 and September 2013 to identify core themes to guide the revision process. Six themes emerged, including:

- Maintain or restore the forest's unique landscapes and features;
- Improve the quality of life and health for the public;

- Respond to key challenges, such as maintaining fire-adapted natural systems, responding to climate change and natural disturbances, reducing non-native invasive species, controlling the impacts of disease and insect outbreaks, and managing increasing demand for recreational opportunities;
- Maintain existing and develop new collaborative partnerships to share operational and planning resources;
- Develop a monitoring strategy and rapid response framework; and
- Integrate and coordinate resource management for multiple uses.

Increasing pressures on the forest, such as a growing regional population, increasing urban development, and invasive species establishment, are compounded by a changing climate. As directed by the 2012 USFS Planning Rule, this Forest Plan revision explicitly incorporates climate change. In developing the plan, the USFS used TACCIMO (Template for Assessing Climate Change Impacts and Management Options) to evaluate climate impacts in the region. Warming temperatures, rising sea levels, severe tropical storms, flooding, and droughts are projected to negatively affect the region. In collaboration with the Eastern Forest Environmental Threat Assessment Center, the forest also identified broad-scale adaptive management strategies to help increase ecosystem resilience to climate change.

Project Outcomes and Conclusions

The plan emphasizes restoring and maintaining ecosystems that are resistant to change, and creating migration pathways and enhancing habitat connectivity to allow for species migrations in response to climate change. Aquatic connectivity is of particular concern for the Francis Marion National Forest, but sea level rise combined with extensive ditching and dikes on the landscape increases the extent that saltwater can penetrate inland freshwater courses. Increasing saltwater extent may reduce the range of freshwater species and/or increase invasive species risk. For example, lionfish can decimate local aquatic populations and are thought to have a high tolerance for low salinity, and may move further inland as sea levels rise. To monitor these types of impacts and to promote resilient management, the Forest Plan encourages adaptive management and lays out a specific monitoring framework, including a metric that evaluates how climate change impacts (drought, sea level rise, and storms) affect restoration success. The plan was initially released in August 2016. An updated revised plan and associated Final Environmental Impact Statement was released in January 2017, and went into effect on May 1, 2017.

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Developing a Structured Decision-Making Model to Facilitate Adaptive Dam Management

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Project Summary

Researchers at the Tennessee Cooperative Fishery Research Unit and Tennessee Tech are developing a structured decision-making model to guide adaptive dam management at the Tims Ford Dam on the Elk River in Tennessee. This model will help optimize dam operations to mitigate negative effects of cold reservoir water release on downstream native aquatic species and sport fish while maintaining human flood protection and hydropower generation opportunities. If successful, this pilot study will facilitate the creation of similar models for dams elsewhere in the state, and lay the foundation for incorporating climate information into future model updates to enhance overall management resilience.

Project Background

The rivers and streams of Tennessee harbor a highly diverse population of freshwater mussels and aquatic species, as well as support a large sport fishing industry for species such as bass and non-native trout. However, many of Tennessee's rivers are extensively dammed to provide hydropower generation, water supply, and flood protection for communities in this water-rich state. Dam-induced habitat fragmentation, as well as cold-water release from storage reservoirs above these dams, are threatening many native aquatic fauna that are adapted to warm water temperatures, leading to numerous imperiled and endangered species listings. In addition, cold-water releases are affecting economically important sport fishing species.

In an attempt to find a balance between hydropower, flood protection, and aquatic species needs, the USFWS, Tennessee Valley Authority, and the Tennessee Wildlife Resources Agency approached the Tennessee Cooperative Fishery Research Unit for help. Using a combination of grant and state funding totaling close to $280,000, the Tennessee Cooperative Fishery Research

Unit, in collaboration with Tennessee Tech, is developing, implementing, and optimizing a structured decision-making model for Tims Ford Dam on the Elk River in south-central Tennessee. This model is designed to serve as a management guide to improve dam operations to optimize conditions for downstream fish species such as the endangered Boulder Darter and expand their distribution while maintaining flood protection and hydropower opportunities.

Project Implementation

To guide development of the structured decision-making model (SDMM), researchers first collected a variety of ecological and hydrological field data. Researchers from the Fisheries Unit and Tennessee Tech were able to obtain water flow and quality data from the Tennessee Valley Authority. However, gathering ecological data proved to be much more time consuming. To generate an accurate SDMM, researchers had to gather ecological information on focal species' occupancy, life history, and current range. Limited monitoring data was previously available, so the research team had to generate and test different species detection techniques and survey protocols, and create species occupancy models. Although gathering this field data took a long time, it was a critical part of the process. The information and protocols generated from this pilot study can likely be applied to other areas, and will be used to monitor adaptive dam management impacts on Elk River fauna.

Researchers also gathered information related to current dam management. They talked with dam operators to identify hydropower needs, flood protection and flood period requirements, and to better understand current operating procedures. By identifying current management parameters, researchers were able to identify opportunities for altered flow management that still meet operational requirements.

Hydrological, ecological, and management data are being incorporated into a final structured decision-making model. This particular SDMM will take the form of a "Look Up" table. Given observed environmental conditions (i.e. season, month, day, weather), management needs (e.g., power release, flood protection), and the current occupancy status of aquatic species, the table provides specific dam operation instructions. For example, the table will give instructions on how much water to release during that day, and in what fashion (i.e. from the top, bottom, or middle of the dam, or through turbines, which may influence water temperatures and turbidity). Management directives will change daily and seasonally, essentially providing guidance for all potential scenarios on the river in a given day. Short-term modeling simulations indicate that adaptive dam management guided by the SDMM will benefit both ecological and human communities.

Project Outcomes and Conclusions

In early 2016, the Fisheries Unit was in the last stages of model finalization, with plans to present the model to state wildlife and TVA officials in the spring of 2016, along with different species detection and survey protocols. If accepted, the TVA and state wildlife agency will implement the SDMM and monitor downstream species to see if adaptive dam management, guided by the SDMM, helps improve species persistence, dispersal, and colonization. If successful, this project could lead to the creation of a structured decision-making model for many, most or all dams in Tennessee, which would not only benefit native and sport fishing species but help mitigate conflicts between various water users. However, developing individual SDMMs will likely require extensive ecological surveying and monitoring to provide the baseline ecological data needed to generate a robust, basin-specific SDMM.

In future refinements of this and other models, Fisheries Unit researchers hope to integrate climate change data (e.g., changing hydrologic flow regimes) to help reduce the vulnerability of native species and human communities to climatic events, such as floods and droughts. Ideally, the SDMM could outline specific dam-management protocols for drought years, 100- and 500-year flood events, and be adjusted to accommodate annual climate variability (e.g., wet/cool years vs. dry/warm years). To successfully incorporate this type of information into the SDMM, researchers believe they will need more available and accessible data related to climate trends and projections, particularly floods and droughts.

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Identifying and Reducing Climate Risks to Water Resources in an Eastern Virginia Water Utility

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Project Summary

Newport News Waterworks is a water provider for several cities and counties in the Mid-Atlantic Coastal Plain of Eastern Virginia near the mouth of the Chesapeake Bay. Climate change is projected to cause issues for local water supply and quality. The utility has worked on a number of impacts studies, capital improvement projects, and water conservation outreach efforts to help improve its activities in light of a changing climate.

Project Background

The City of Newport News owns and operates Waterworks, a regional water utility that services over 400,000 residents in three cities and two counties in the region. Major surface water sources include the Chickahominy River and several reservoirs, including Diascund Creek, Little Creek, Waller Mill, Lee Hall, Skiffe's Creek, and Harwood's Mill. Changing precipitation patterns and rising sea levels are issues of concern for water demand, supply, and quality in the region. Changing precipitation patterns are expected to cause both more intense rainfall and more frequent and intense droughts. Increased rainfall will likely increase sedimentation into surface water supplies and may damage water resources infrastructure, while more drought is projected to result in reduced surface and groundwater supplies. Sea level rise is expected to inundate the service area, causing saltwater intrusion into surface and groundwater supplies, as well as exacerbate local land subsidence rates.

Project Implementation

Sea Level Rise and Increased Salinity Study

In 2011, USGS and the City of Newport News conducted a study to evaluate the impacts of rising sea levels on the salinity of the York and Chickahominy Rivers. Both of these rivers are key tributaries for Chesapeake Bay and its estuaries, and the Chickahominy River also serves as a major drinking water source for Newport News. The joint study used estuarine models, the Three-Dimensional Hydrodynamic-Eutrophication Model (HEM-3D), and three different sea level rise scenarios (30, 50, and 100 cm) to model how increasing sea levels and freshwater flow volumes influence river salinity concentration gradients. The study found that even with normal flow regimes, sea level rise will likely increase mean salinity concentrations for both rivers, which could be problematic for the intake site that provides 30-70% of the region's drinking water supply. In addition, the study highlighted how flow regimes moderate river salinity; higher flows effectively minimize river salinity, while low flows exacerbate increasing salinity and allow salt water to travel further upstream into these freshwater systems. For example, salinity concentrations near the Newport News drinking water intake are projected to more than double during dry, low-flow years, which could reduce both the quality and quantity of water available for human consumption and degrade important freshwater habitat.

Saltwater Contamination: Monitoring and Capital Improvements
Waterworks utilizes a variety of strategies to mitigate saltwater contamination of drinking water supplies. For example, it conducts daily salinity monitoring of intake river and water storage reservoirs, and established a salinity threshold to guide pumping termination. Constant monitoring and threshold controlled pumping maximizes water storage without compromising water quality. Waterworks also operates a desalination facility. This facility typically operates at base levels to minimize cost, but operations can be scaled up during times of drought to supplement surface water sources, ensuring a consistent supply of clean water for Newport News residents.

In addition to its normal operations, Waterworks is also preparing for climate change impacts. For example, in response to climate change and potential salinity increases in its intake river, Waterworks is in the process of rebuilding Walker Dam, the saltwater intrusion prevention dam on the Chickahominy River. As a hedge against increased sea levels and larger storm surges and tidal fluctuations, the dam now includes designs for flash fjords, structures that are temporarily raised to increase dam height and prevent saltwater intrusion into the upstream intake site. Waterworks is also rebuilding and refurbishing its other dam structures; although much of this work was mandated due to aged dams and elevated flood risk due to changes in population size and location, Waterworks has capitalized on these mandated updates by choosing to incorporate climate resiliency into refurbishment designs. For example, its refurbished dams are now designed to better withstand 100-year storm events and storms of greater intensity and duration. In addition to operational and structural resiliency, Waterworks also promotes resilient water management through its water conservation and watershed health programs.

Water Conservation and Public Outreach
Although Waterworks has always promoted an ethic of stewardship, it formally started a Conservation program in the 1980s, which has enjoyed extremely high success in reducing regional water use. For example, single-family home water consumption dropped from 195 gallons per day to 134 gallons per day (-31%) between 1997 and 2012, and the largest regional water consumer, Anheuser Busch, has reduced its water use by 50%. Voluntary water conservation has been so successful that Waterworks ended up abandoning a reservoir construction project, as conservation has more than met increasing demand. For example, Waterworks has seen an over 50% reduction in water use, even with a population growth of more than 30,000 people.

In addition to its general conservation outreach via newsletters, social media, regional events, and collaboration with the regional conservation initiative HR GREEN, Waterworks also promotes conservation through residential rain barrel workshops. Via partnership with the Newport News Public Works Department and regional Master Gardeners, Waterworks provides rain barrel workshops where participants can learn about water conservation, Waterworks operations, and get detailed information on rain barrel construction, installation, and use. Workshop participants are given a pre-cut rain barrel that has been refurbished from its previous food transportation role, promoting reuse and recycle themes. Virginia receives abundant rainfall, so the Rain Barrel Workshops are aimed at promoting the use of natural water for outdoor landscaping needs, rather than using treated water that costs both the utility and the customer money.

Waterworks is also in the process of updating how it manages water conservation during drought periods. Waterworks operates on a 4-tier drought restriction program, ranging from voluntary reduction periods to extreme restrictions. During drought periods, Waterworks conducts outreach through newsletters and local partnerships (e.g., garden centers, homeowners associations, etc.) to encourage water use reductions. Waterworks also adds a line item to bills that increases surcharges if people overuse water. For example, customers are currently are allotted a "lifeline" of 600 cubic feet of water per billing cycle. If consumers exceed this water allotment during restricted periods (e.g., during droughts), they are charged a surcharge, which can range anywhere from 15-45% of their typical bill depending on the drought seriousness and the extent to which they overuse. However, water conservation has been so significant across the region that Waterworks is debating lowering this lifeline to 400 cubic feet, which would lower overall water use and further encourage conservation during drought periods to avoid surcharges. In addition, Waterworks is debating making its water conservation exemption process more rigorous (e.g., by requiring documentation of current conservation practices) to ensure that only those businesses and individuals who truly need consistent or above average water use (e.g., for health reasons or maintenance of livelihoods) would be exempt from reducing water usage during drought periods. These discussions will all be incorporated into the current update of the utility's Water Conservation Management Plan.

Project Outcomes and Conclusions

From source to tap, Waterworks practices responsible and resilient water management. Its Watershed Health program protects water quality throughout the entire 12,000-acre watershed using land use best management practices, while its Conservation program reduces water overuse and helps customers and consumers appreciate the holistic value of regional water sources. The road to achieving sustainable conservation has not been easy. Waterworks discovered that using only volumetric and monetary incentives to reduce water use resulted in an unsustainable cash flow for the utility; consumers reduced their water use, resulting in less revenue, but operational costs for the utility did not decrease. Waterworks has now stabilized its revenue stream via mainly fixed, rather than volumetric, rates and by promoting the holistic value of water rather than simply its monetary value. A steady cash flow allows for continual and updated conservation programming and provides necessary base funds to explore more sustainable treatment and infrastructure options.

In between source and tap, Waterworks strives to perfect management by investing in sustainable and resilient operational structures and strategies to reduce water vulnerability and maximize availability. Through its various programs, detailed monitoring, and ongoing updates, Waterworks serves as a great example of a resilient and adaptive water utility.

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A Climate-Informed Update of Virginia's State Wildlife Action Plan

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Project Summary

To better understand and address climate change in its 2015 State Wildlife Action Plan update, the Virginia Department of Game and Inland Fisheries (VA DGIF) applied downscaled climate change modeling in a vulnerability assessment for 20 different species. Vulnerability assessment information and regional climate projections were integrated into the recently published plan, which takes a habitat-conservation based approach to wildlife management, provides critical management and climate information at relevant local scales, and outlines monitoring strategies for evaluating conservation action effectiveness. Climate models have also been used to identify priority refugia across all conservation lands in Virginia, including those under federal, state, local, and NGO management. In addition, the VA DGIF is actively working to reduce non-climate stressors in aquatic and riparian habitats to bolster habitat resilience in the face of climate change.

Project Background

The Virginia Department of Game and Inland Fisheries (VA DGIF) manages over 30,000 aquatic and terrestrial species, including threatened and endangered (T/E), game and non-game, and migratory species. Game and T/E species have their own revenue streams and constitute a minority of species under VA DGIF management. In 2000, Congress established the State and Tribal Wildlife Grants Program to provide funding for managing species other than game and T/E species. To receive State and Tribal Wildlife Grant funds, each state is required to complete a State Wildlife Action Plan.

Virginia completed its original action plan in 2005, identifying 925 species of greatest conservation need, 75-80% of which are either aquatic or riparian species. The 2005 plan also identified rivers as crucial habitat and a conservation priority given a warmer future with variable precipitation. Although the 2005 plan mentioned certain climate change impacts such as sea level rise and warming temperatures, it generally gave no definitive guidelines and principles for managing wildlife and fisheries under a changing climate. Given potential climate change impacts on Virginia's wildlife and fish species, including range shifts and habitat contraction and degradation, the VA DGIF wanted to more explicitly plan for and incorporate climate change into its State Wildlife Action Plan update in 2015. Other goals of the plan update process included taking a habitat approach to conservation management and threat evaluation, enhancing relevance and management opportunities at the local scale, prioritizing species and conservation actions, representing multiple stakeholders and partners, and developing a system for measuring conservation action effectiveness.

Funding for the 2015 State Wildlife Action Plan update was received from the State and Tribal Wildlife Grant program. As a part of the update, species-specific climate change modeling totaling roughly $193,000 was funded by a grant from the Doris Duke Charitable Foundation with additional funding and personnel support from the National Wildlife Federation.

Project Implementation

After the 2005 State Wildlife Action Plan was published, the VA DGIF engaged in several efforts to improve understanding of species and habitat vulnerability to climate change. From 2007-2008, in collaboration with the National Wildlife Federation and the Virginia Conservation Network, the VA DGIF held two stakeholder workshops to identify general climate change adaptation options for the state. The final report, published in 2009 as *Virginia's Strategy for Safeguarding Species of Greatest Conservation Need from the Effects of Climate Change*, discusses research needs and goals for climate-informed wildlife management, and discusses potential adaptation options identified by workshop participants. Many specific adaptation options are presented under three general adaptation strategies: (1) conserve species and habitats as climate changes, (2) address data and modeling needs related to climate change, and (3) expand outreach and education efforts. Under the second strategy, one key action was to "produce climate modeling and associated wildlife threats and vulnerability assessment for Virginia."

To address the need for more explicit vulnerability information for wildlife and fish species, the VA DGIF collaborated with the National Wildlife Federation, Virginia Tech's Conservation Management Institute, and Kutztown University to develop dynamically downscaled climate models and conduct a species vulnerability assessment. Models for the Mid-Atlantic Region (including West Virginia, Virginia, Maryland and Delaware) were downscaled to a 10 square km grid scale resolution, and provided data on 20 different climate variables for current, mid- and late-century time frames (1990-1999, 2055-2060 and 2090-2095), based on two separate IPCC climate scenarios representing lower and higher emissions (B1 and A1F1). In excess of the 20 variables that could be directly modeled, an additional 10-12 climate-related variables (e.g., soil moisture) could be generated based on model data.

This downscaled information was applied in a vulnerability assessment of 20 species. Species included those of greatest conservation need or species identified in the 2005 State Wildlife Action Plan, and were selected in part from guidance from state and federal biologists and in part to represent a broad array of habitat types, species groups, and climate sensitivity. An independent model was run for each species, incorporating data related to current distribution, known climatic tolerances, and estimated future distributions predicted under climate change. A series of species distribution maps under current and future conditions were generated for each species, and published in the 2013 report *Virginia's Climate Modeling and Vulnerability Assessment: How Climate Data Can Inform Management and Conservation*.

Modeling results revealed interesting projections for riparian and aquatic species. For example, riparian tree species eastern hemlock and yellow birch will likely exhibit different responses to climate change, with eastern hemlock habitat suitability declining by mid-century while yellow birch remains largely unaffected. Shifts in the distribution of these species could impact stream shading and water temperature in high-elevation cold-water streams, with ramifications for aquatic biota. Mirroring these changes, modeling results for cold-water fish species (represented by brook trout) indicate that cold-water fish will likely suffer significant habitat reductions due to decreasing snow cover and soil moisture, increasing temperature, and more frequent high-volume precipitation events. By comparison, warm-water fish species (represented by the Roanoke log perch) and freshwater mussels (represented by the James River Spiny Mussel) were projected to experience increasing habitat availability as a result of climate change, although water quality issues related to increased runoff, erosion, and water temperature could be potential issues of concern.

Staff had less confidence in model results generated for aquatic species due to the high number of factors that influence aquatic systems, and this modeling effort did not include factors related to land use or population growth. Overall, findings from the vulnerability assessment highlighted the importance of maintaining current healthy species populations and healthy habitats to buffer future climate impacts and create management opportunities in the long term.

Project Outcomes and Conclusions

Climate change information and climate-informed management actions based on the modeling results were successfully integrated into Virginia's recently published 2015 State Wildlife Action Plan. This plan takes a habitat-based approach to analyzing threats and developing conservation actions, which ensures that multiple species will benefit from any one conservation activity. The plan also breaks down management actions according to 21 local regions, which roughly mirror Planning District Commissions across the state. Organizing the plan in this manner should facilitate action by both the state and other key stakeholders, leveraging conservation opportunities and maximizing collaborative conservation.

Climate change information is presented both at the state and local level in the updated plan. An analysis of statewide trends is presented at the beginning of the report, and each local summary includes a synthesis of relevant climate threats and potential management responses for priority habitats within that area. Potential effectiveness metrics are also presented for each of the 21 regions to facilitate conservation project monitoring. The VA DGIF hopes that in the near future, both agency and non-agency conservation projects can be uploaded to the Wildlife TRACS (Tracking and Reporting Actions for the Conservation of Species) system to facilitate adaptive management in the face of changing conditions.

The VA DGIF is now working on generating, interpreting, and compiling additional climate change data to supplement information generated in the species vulnerability assessment. It hopes to use this information to begin to actively manage for future climate shifts. For example, knowing that the state may see a shift in dominant riparian species, the department wants to develop critical management questions in regards to maintaining riparian vegetation for stream temperature regulation. By considering questions like what species can take the place of currently dominant riparian shade trees to maintain stream shading, when replacement plantings should begin, and what partnerships and resources are needed, the VA DGIF hopes to shape future management action. In the long term, the VA DGIF hopes to make climate change adaptation an integral part of its 2025 Wildlife Action Plan update.

The VA DGIF has also applied its climate models in a broader landscape conservation context via the Conservation Lands and Climate Assessment Project. The VA DGIF owns and manages more land than any other state agency in Virginia, and as an entity making significant financial investments via land purchases, wanted to better understand how ecological land value may change in the future. Using $127,000 provided by the State and Tribal Wildlife Grant program, the State of Virginia and an in-kind match from the Virginia Tech Climate Modeling Institute, the VA DGIF identified all parks, refuges, easements, wildlife management areas, and other conservation areas under state, federal, and NGO partner ownership, representing Virginia's "conservation lands portfolio." Current and future climate conditions were modeled across this portfolio to identify how conditions may change across the state, which habitats and species may be most resilient, and where potential habitat refugia may exist. This landscape-scale information will be very important for climate-informed management of different wildlife and aquatic species, particularly those that may benefit from assisted migration and/or those that require in-place conservation. More information on the specific modeling done in this effort is available in the 2015 State Wildlife Action Plan, and interested parties can also download GIS shapefiles of conservation lands in Virginia via the Conservation Lands Database website.

Concurrent to climate modeling and adaptation efforts, the VA DGIF is also working with landowners to mitigate non-climate impacts on state watersheds in order to enhance overall habitat resilience. Through State and Tribal Wildlife Grants and other programs and partnerships, the VA DGIF works with public and private landowners to collaboratively finance waterway rehabilitation on private land. This program primarily focuses on reducing nitrogen, phosphorus, sediment, and contaminant delivery to streams, and activities are concentrated in several high-priority watersheds that are experiencing significant human impacts and that also contain many rare and imperiled species (e.g., Tennessee River, the Upper James River, and the Roanoke River). Sample activities include installing cattle fencing, creating riparian buffers, restoring stream banks, and restoring streams through creating meanders. Restoration projects have cost anywhere from $5,000 to $50,000, and are funded by a combination of outside sources, the state level Fish and Wildlife Service, sport fish restoration money, State and Tribal Wildlife Grant funds, and funds from the State of Virginia. An example project includes restoration of a cut bank to reduce sediment delivery on the South Fork of the Shenandoah River in partnership with the Town of Elkton. By redesigning the stream channel and shoreline, and establishing a forested riparian buffer, the partnership hopes to improve water quality to benefit scores of Virginia's species of greatest conservation need, the Town, and downstream landowners, as well as boaters, anglers, wildlife watchers, and other outdoor enthusiasts. The VA DGIF hopes that this type of collaborative effort will build positive relationships between private landowners and the state, laying the groundwork for similar collaborative efforts in the future.

References/Links

Virginia's 2015 State Wildlife Action Plan: http://bewildvirginia.org/wildlife-action-plan/draft/
Virginia's Strategy for Safeguarding Species of Greatest Conservation Need from the Effects of Climate Change: http://bewildvirginia.org/climate-change/
Virginia's Climate Modeling and Vulnerability Assessment: How Climate Data Can Inform Management and Conservation: http://bewildvirginia.org/climate-change/virginias-climate-vulnerability-assessment.pdf
Conservation Lands Database: http://www.dcr.virginia.gov/land-conservation/tools02a

Citation

Reynier, W. 2017. *A Climate-Informed Update of Virginia's State Wildlife Action Plan* [Case study on a project by the Virginia Department of Game and Inland Fisheries]. Available on CAKE: http://www.cakex.org/case-studies/climate-informed-update-virginias-state-wildlife-action-plan (Last updated December 2017)

Climate-Informed Watershed Restoration on the Elizabeth River

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Project Summary

The Elizabeth River Project is practicing climate-informed restoration of the Elizabeth River and adjacent watersheds in Virginia. By taking sea level rise into consideration in its collaboratively developed Watershed Action Plan and restoration projects, as well as engaging significant stakeholders through community outreach and education, the project is improving the environmental health of the Elizabeth River.

Project Background

The Elizabeth River in southeast Virginia, a tributary of Chesapeake Bay, has a long legacy of military and industrial use. Sediment contamination, water pollution, historic tidal wetland loss, and altered channel morphology are all significant problems undermining the health of this watershed and adjacent ecosystems in Chesapeake Bay, reducing the value of these aquatic resources for local communities. In addition, sea level rise threatens existing habitats and human communities.

Founded in 1993 to address pollution issues in the Elizabeth River, The Elizabeth River Project (ERP) is a nonprofit organization using targeted restoration, public outreach, and education to improve the health of the Elizabeth River. To address future challenges, the ERP works to include sea level rise projections in its work and outreach to ensure that projects and partner initiatives are resilient to future increases in sea level. A majority of ERP work is funded by federal and state grants, as well as by private donations and targeted funding campaigns.

Project Implementation

One of the first achievements of the Elizabeth River Project was the development of a Watershed Action Plan for the Elizabeth River corridor. This plan guides restoration goals and projects along the waterway, and was developed collaboratively with over 100 river stakeholders, including industry, community members, reservoir managers, and state and local governments. The first Watershed Action Plan was published in 1996, and has been revised four times to reflect changing watershed conditions and priorities, with the most recent version being published in 2015. The 2015 plan acknowledges the region's vulnerability to sea level rise, and makes several recommendations to enhance the resilience of the Plan's goals and activities. For example, it recommends protecting upland space for wetland migration and working with local governments to restrict development in low-lying areas.

The ERP uses a variety of data to inform restoration projects and future Water Action Plan updates. Regional data is sourced from the Virginia Department of Environmental Quality, the Virginia Institute of Marine Sciences, the EPA, and field observations (e.g., sediment samples, elevation measurements, biological benchmark surveys, bathymetry surveys, sediment SONAR surveys). The ERP also uses monitoring data from existing restoration projects, historical local knowledge, and old fire and sand bar maps; these latter resources are used to enhance understanding of historic pollutant exposure and river management.

The Elizabeth River Project has led a variety of collaborative implementation projects to achieve restoration goals outlined in the Watershed Action Plan. The ERP attempts to design restoration projects to be resilient to climate impacts; for example, where possible, wetland restoration projects are designed to accommodate upland retreat in response to rising sea levels, and feature salt-tolerant vegetation to ensure that the marsh can survive periodic inundation from increasing storm surge. Restored marshes not only improve water quality and provide habitat, but also protect adjacent communities.

In addition to restoration work, the Elizabeth River Project also engages in a variety of education and community outreach programs. The ERP acts as a formal pollution prevention advisor for regional industries, government, and citizens. It also established the River Star Homes and Businesses Program, which encourages industries and homeowners to improve on-site river and riparian habitat and reduce on-site nutrient loads coming from their land. The ERP also runs the River Star Schools Project, bringing STEM and river education to local youth.

In all of its work, the ERP engages with a variety of partners to achieve goals and activities identified in the Watershed Action Plan. Critical partners include the NOAA Restoration Center, EPA Region 3, the National Fish and Wildlife Foundation, local cities and municipalities, the Virginia Department of Forestry, and the Virginia Port Authority.

Project Outcomes and Conclusions

Since 1997, The Elizabeth River Project and partners have completed many activities outlined in the Watershed Action Plan. They've completed over 100 collaborative wetland restoration and natural storm buffer projects in the watershed, as well a significant sediment cleanup project, which replaced 16,000 cubic yards of contaminated river sediments with suitable habitat. This project, in particular, has greatly enhanced community resilience to climate change impacts. In 2009, a newly constructed 7-acre wetland at the sediment remediation site not only survived a storm with record-breaking storm surge, but also prevented flooding onto adjacent industrial property.

All restoration projects are monitored by ERP staff or partners to better understand overall watershed health trends and responses to restoration activities. Monitoring metrics are largely related to water quality and biotic activity, diversity, and health, as well as comparing how project design compares to actual project implementation. Monitoring data and other regional water quality information are used to improve restoration design and to inform Watershed Action Plan updates. The Elizabeth River Water Action Plan is updated on a 5-year cycle to reflect changing conditions and priorities within the watershed; in the past year, over 100 stakeholders completed a plan update. Monitoring data is also used to develop State of the River reports, which provide snapshots of river health trends and significant restoration, education, and outreach projects being conducted by the ERP. The most recent State of the Elizabeth River report was published in 2014.

The ERP is also using restoration success to enhance its educational programs. For example, the ERP helped restore the 40-acre Paradise Creek wetland and install an educational pavilion, which is now used for local school fieldtrips. With help from Virginia Dominion Power, the ERP also retrofitted an off-the-grid steel barge located on the Elizabeth River. Similar to the wetland, this nontraditional classroom is used to enhance STEM education, to emphasize how successful restoration benefits human communities and habitats, and to demonstrate how partnerships between industry, the community, and environmental groups can accomplish mutually beneficial goals.

The ERP has been very successful in working with nontraditional partners, such as Virginia Dominion Power. In partnership with the ERP, this riverside coal power company has funded many outreach and education projects to reach a diverse group of local students. The utility also actively participates in the River Star Homes and Businesses Program and leads several other sustainability efforts. The ERP credits its success in working with such diverse stakeholders to focusing on on-the-ground solutions to local problems, and by leveraging what opportunities exist. Moving into the future, the ERP plans to continue to implement goals and activities outlined in the Watershed Action Plan.

References/Links

Watershed Action Plan: http://www.elizabethriver.org/sites/default/files/ERP-watershed-action-plan_0.pdf
State of the Elizabeth River 2014:
http://media.wix.com/ugd/8de0fd_6fd8647352d84f91a842eaf0c37da40a.pdf
River Star Program**:** http://www.elizabethriver.org/#!be-a-river-star/c1cr7

Citation

Reynier, W. 2017. *Climate-Informed Watershed Restoration on the Elizabeth River* [Case study on a project by the Elizabeth River Project]. Product of EcoAdapt's State of Adaptation Program. Available on CAKE: http://www.cakex.org/case-studies/climate-informed-watershed-restoration-elizabeth-river (Last updated December 2017)

Integrating Climate Change into Plan Revisions at El Yunque National Forest

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Project Summary

In 2012, the USFS released a Planning Rule requiring the integration of climate change impacts, vulnerability, and adaptation into revisions of forest management plans. The El Yunque National Forest began the forest plan revision process in 2014. A draft plan to guide forest resource management was released in September 2016; the final plan is expected to go into effect in 2018.

Project Background

The 29,000-acre El Yunque National Forest in northeastern Puerto Rico is the only tropical rain forest in the U.S. National Forest system. Located in the Sierra de Luquillo Mountains, the forest features diverse vegetation types, waterfalls, and pools that provide habitat for over 180 animal and 636 plant species. The mountains are a major water source for the island, supplying more than 20% of the municipal water source with approximately 46 million gallons of water withdrawn per day.

Every national forest is guided by a land and resource management plan (commonly known as a forest plan) – a document that sets forth guiding management principles on a 10-15 year time horizon. Since 2014, the El Yunque National Forest has been undergoing a forest plan revision – the first revision of the original forest plan released in 1997. The original plan focused on conservation to protect the unique biological and ecological diversity of the forest. The revised plan focuses on an integrated approach to ecological, social, and economic sustainability, and addresses evolving forest conditions, issues, and trends.

Project Implementation

In developing the plan, the forest engaged in several outreach efforts with other federal, state, and local agencies and public stakeholders to identify core themes to guide the revision process. Five themes were developed, including:

- Promote a stronger regional identity using an “all-lands approach”;
- Provide for healthy ecosystems;
- Incorporate collaborative adaptive management principles;
- Define a new recreation, access, and tourism system; and
- Increase regional environmental literacy and educate local communities.

The forest is subjected to increasing pressures from urbanization, which has resulted in landscape fragmentation. In addition, increasing drought, wildfire, invasive species establishment, and disease outbreaks are all of concern to forest managers. As directed by the 2012 USFS Planning Rule, the revision explicitly incorporates climate change.

Project Outcomes and Conclusions

The plan emphasizes restoring and protecting ecosystems that are resilient to climate change and other stressors. Desired conditions associated with the forest's climate change response include enhancing longitudinal landscape connectivity to allow species to move upslope from lowland to upland forests as temperature rise; retaining wetlands and ponds to support cool, moist conditions for species and water supply; and managing invasive species. The plan also prioritizes riparian zones as areas that help maintain critical ecosystem functions and services (i.e. water supply and quality), identifying key management strategies such as the prioritization of riparian zones in major streams for land acquisition. Management strategies associated with water resources in the forest include no further authorizations for consumptive water intakes and protecting surface and groundwater supplies from physical, chemical, and biological pollutants. The draft plan was released for public comment in September 2016. The final plan is expected in 2018.

References/Links

El Yunque National Forest Plan (DRAFT):
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd517942.pdf

Citation

Gregg, R.M. 2017. *Integrating Climate Change into Plan Revisions at El Yunque National Forest* [Case study on a project by the El Yunque National Forest]. Product of EcoAdapt's State of Adaptation Program. Available on CAKE: http://www.cakex.org/case-studies/integrating-climate-change-plan-revisions-el-yunque-national-forest (Last updated December 2017)

Guide for Selecting Tools to Support Climate-Informed Water Resources Action

The purpose of this section is to describe the current suite of tools available to support adaptation action in water resources management, planning, and conservation. The number of tools applicable to climate-informed water resources management is continually growing; here we present a selection of tools, all of which are available on CAKE. Where possible, we provide examples of the tools in use both from within and outside the region.

Methodology

Tools were identified by compiling and reviewing resources from various databases, such as CAKE, the EBM Tools Network, and Digital Coast. We reviewed tools that are applicable to a variety of sectors, projects, and regions. Each tool was categorized by the following criteria:

- **Accessibility:** Open access (i.e. free of charge), Proprietary (i.e. uses restricted)
- **Tool Type**: Visualization, Modeling, Decision Support, Communications/Outreach, Monitoring, Portal
- **Phase of Adaptation[35]:** Awareness, Assessment, Planning, Implementation, Integration, Evaluation, Sharing
- **Water subsector:** Water quality, water supply and storage, water demand/use, water delivery (ecosystems/infrastructure)
- **Water Resource Types:** Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
- **Sectors:** Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, engineering, environmental justice, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, public health, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
- **Intended Audience:** Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists

[35] Learn more about EcoAdapt's Adaptation Ladder of Engagement™ at http://www.ecoadapt.org/programs/state-of-adaptation/adaptation-ladder

Tool Profiles

This section includes individual profiles of each of the 51 tools identified through this project. In addition to resource portals (11 total), the tools included focus on modeling (22), visualization (19), decision support (13), monitoring (9), and communications/outreach (8). With respect to water resources, the tools support information and data sharing on water supply (29), water demand and use (13), water quality (31), and water delivery (38) (Table 13).

Table 13. List of tools evaluated that can support climate adaptation action.

Tool Name	Water Supply	Water Demand and Use	Water Quality	Water Delivery
Adaptation Strategies Guide for Water Utilities	✔	✔	✔	
Advanced Hydrologic Prediction Service	✔	✔	✔	✔
Aqueduct Water Risk Atlas	✔	✔	✔	
Arc Hydro	✔			
ASR Recovery Initiation Index	✔			
BASINS CAT (Better Assessment Science Integrating Point & Non-Point Sources Climate Assessment Tool)	✔		✔	✔
C-CAP Land Cover Atlas				✔
CanVis				✔
Climate Adaptation Knowledge Exchange (CAKE)	✔	✔	✔	✔
Climate Change and Water: Resources and Tools Page	✔	✔	✔	✔
Climate Change Resource Center	✔		✔	✔
Climate Explorer	✔		✔	✔
Climate Resilience Evaluation & Awareness Tool (CREAT)	✔			✔
ClimateWizard	✔	✔	✔	✔
Coastal Change Hazards Portal				✔
Coastal Community Resilience Index			✔	✔
Coastal County Snapshots				✔
Coastal Flood Exposure Mapper			✔	✔
Coastal Resilience				✔
Creating Resilient Water Utilities	✔	✔	✔	✔
Drought Impact Reporter	✔		✔	
Drought Management Database	✔	✔	✔	✔
Drought Risk Atlas	✔			
Extreme Water Levels			✔	✔
Federal Support Toolbox	✔	✔	✔	✔
Flood Inundation Mapper			✔	✔
Flood Inundation Maps				✔
Flood Resilience: A Basic Guide for Water and Wastewater Utilities	✔		✔	✔
Georgia Water Toolkit	✔		✔	✔
Habitat Priority Planner				✔

Tool Name	**Water Supply**	**Water Demand and Use**	**Water Quality**	**Water Delivery**
i-Tree	✔		✔	✔
Inundation Analysis Tool			✔	✔
Local Climate Analysis Tool (LCAT)	✔			
Low Impact Development (LID) Atlas			✔	✔
National Aquatic Resources Surveys	✔			✔
National Stormwater Calculator			✔	✔
National Water Information System	✔	✔	✔	
OpenNSPECT (Nonpoint Source Pollution and Erosion Comparison Tool)			✔	
Sea Level Affecting Marshes Model Visualization (SLAMM) View				✔
Sea Level Rise Viewer				✔
Soil Climate Analysis Network (SCAN)	✔			
Storm Water Management Model Climate Adjustment Tool (SWMM-CAT)			✔	✔
Surging Seas				✔
Template for Assessing Climate Change Impacts and Management Options (TACCIMO)	✔		✔	✔
Tidal Flooding				✔
U.S. Drought Portal	✔		✔	
Water Conservation Tracking Tool		✔		
EPA Water Erosion Prediction Project Climate Assessment Tool (WEPPCAT)			✔	
Water Evaluation and Planning System (WEAP)	✔	✔	✔	✔
Water Supply Stress Index (WaSSI) Ecosystem Services Model	✔	✔		✔
Watershed Central, Handbook for Developing Watershed Plans to Restore and Protect our Waters, and Watershed Plan Builder	✔		✔	✔

Adaptation Strategies Guide for Water Utilities

https://www.epa.gov/sites/production/files/2015-04/documents/updated_adaptation_strategies_guide_for_water_utilities.pdf

Developed by: EPA
Contact Information: Office of Water Online Contact Form, http://water.epa.gov/contactus.cfm

Description: The Adaptation Strategies Guide for Water Utilities is a PDF document designed to help water utility managers (e.g., drinking water, wastewater, stormwater) understand regional climate change issues and explore potential adaptation options. The guide consists of three types of linked informational briefs, a glossary explaining potential adaptation options in more depth, and an adaptation planning worksheet (with completed examples) intended to guide users through the document and process. The three informational briefs include: climate region briefs, which describe climate change projections and challenges faced in different geographic areas of the United States; strategy briefs, which group adaption options under common climate challenges faced by water managers (i.e. drought, water quality degradation, floods, ecosystem changes, and service demand and use); and sustainability briefs, which discuss adaptation options for specific challenges selected from the climate region briefs or the challenge group briefs in more detail. For example, sustainability briefs discuss sector-specific options, discuss costs associated with implementation, group adaptation options into different categories (i.e. planning, operational, or capital/infrastructure strategies), and provide real-world examples. The Adaptation Strategies Guide for Water Utilities is useful guide for those new to or looking to expand adaptation efforts, as it covers multiple stages of adaptation.

Accessibility: Open access
Tool Type: Decision Support
Water subsector: Water supply, water quality, water demand and use
Water Resource Types: Drinking water, wastewater, stormwater
Sectors: Water utilities, water resources, policy
Intended Audience: Water utility managers (drinking water, wastewater, stormwater), planners, policymakers, local/state/regional authorities

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Advanced Hydrologic Prediction Service

http://water.weather.gov/ahps/about/about.php

Developed By: NOAA National Weather Service
Contact Information: w-nws.webmaster@noaa.gov

Description: The Advanced Hydrologic Prediction Service (AHPS) provides a variety of forecasts from the National Weather Service regarding potential magnitude and uncertainty of flood and drought events. The AHPS offers hydrologic forecasts for close to 4,000 locations throughout the United States, and forecasts can be produced from hours to months in advance. The tool mainly draws upon data from the USGS National Streamflow Information Program (https://water.usgs.gov/nsip), a national network of stream gauges. Users can view information on forecasted flood levels and timing, the probability of a river exceeding minor, moderate, or major flood conditions or exceeding a certain volume, and maps of areas surrounding rivers so that users can identify roads, railways, and other infrastructure that could be affected by flooding. Communities can use the AHPS to be informed about potential flooding and drought risk and impacts, and local officials can use the models to prepare for flood events, evacuate residents, and implement mitigation measures.

Accessibility: Open access
Tool Type: Visualization, Decision Support
Water subsector: Water quality, water supply and storage, water demand/use, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, fisheries, forestry, infrastructure, land use planning, policy, rural/indigenous livelihoods, socioeconomic development, scientific research, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The National Weather Service partners with other federal and state agencies to map the areal extent of flood categories to create flood inundation maps. These maps display the extent of projected flooding expected to inundate streets, buildings, and other infrastructure using the AHPS forecasts at select locations to help emergency managers and planners assess flood risk. Maps are available for several Southeastern cities, including Birmingham, Greenville-Spartanburg, Jackson, Jacksonville, Louisville, Atlanta, Raleigh, Shreveport, Tallahassee, Tampa Bay, and Wilmington.

Aqueduct Water Risk Atlas

http://www.wri.org/our-work/project/aqueduct

Developed By: World Resources Institute
Contact Information: amaddocks@wri.org

Description: The Aqueduct Water Risk Atlas is an online mapping tool that allows users to examine current, emerging, and projected water risks on a global scale. Users can zoom in to a chosen location and overlay water risk with various base layers (e.g., topographical and street maps) to enhance spatial analysis. To analyze current water risk, users can map overall risk, adjust risk based on different contributing industries in their area (e.g., oil and gas, food, textiles), or map individual risk components. For example, they can map different factors that affect physical water quantity (e.g., flood occurrence, drought vulnerability, seasonal variability) and physical water quality (e.g., return flows, upstream land protection), as well as different factors that affect water regulatory and reputational risk. For the latter category, the Atlas maps media coverage, population water access, and threatened amphibian presence, categories that may affect how water management is handled, viewed, and regulated. Users can also map how future water risk may change over a 30-year time period due to climate change and development. Specifically, users can analyze how water stress, seasonal variability, water supply, and water demand may change over three different time horizons (2020, 2030, and 2040) and under two different climate scenarios (optimistic and business as usual). Maps can be downloaded or shared via a permalink. Information generated by the Aqueduct Water Risk Atlas can be used to compare current and projected water challenges, to inform planning efforts, and to inform management in governmental, industrial, and financial sectors, as well as at local scales.

Accessibility: Open access
Tool Type: Modeling
Water subsector: Water quality, water supply and storage, water demand/use
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs
Sectors: Agriculture, aquaculture, conservation/restoration, education/outreach, emergency management/preparedness, energy, engineering, environmental justice, fisheries, forestry, infrastructure, land use planning, policy, public health, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, industry, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Arc Hydro

http://resources.arcgis.com/en/communities/hydro/01vn0000000s000000.htm

Developed By: ESRI - ArcGIS Resource Center
Contact Information: hydroteamrc@esri.com

Description: Arc Hydro is a set of data models geared to support water resources applications. It features two components, the Arc Hydro Data Model and Arc Hydro Tools. This model focuses on surface water dynamics. ESRI provides case studies to inform modeling efforts and provide best practices, along with a number of hydrological tools to further improve the Hydro Data Model. This will allow users to model potential changes in hydrological flow resulting from climate change.

Accessibility: Open access
Tool Type: Modeling
Water subsector: Water supply
Water Resource Types: Watersheds
Sectors: Water resources
Intended Audience: Natural resource managers, water utility managers, planners

Awareness	**Assessment**	**Planning**	Implementation	Integration	Evaluation	Sharing

Example in use: The South Florida Water Management District used Arc Hydro to evaluate the restoration of the Kissimmee River. The river was channelized and drained in the 1960s through the Central and South Florida Flood Control Project; as a result, a number of plant and animal species disappeared (i.e. 90% of wetland waterfowl, 70% of bald eagle nests). The Kissimmee River Restoration Project aims to restore flows to 44 miles of the historic channel and restore 40 mi^2 of riverine and floodplain ecosystem. The South Florida Water Management District is using Arc Hydro to evaluate the re-establishment of pre-channelization hydrologic conditions.

ASR Recovery Initiation Index

http://floridawca.org/node/365

Developed By: Peace River Manasota Regional Water Supply Authority
Contact Information: peaceriver@regionalwater.org

For water systems utilizing aquifer storage and recovery (ASR) for water storage, the ASR Recovery Initiation Index is a spreadsheet-based tool that can help managers decide when to initiate recovery (i.e. pumping of water stored in the aquifer). This Microsoft Excel model incorporates and weights 10 variables related to current water supply, projected future demand, current hydrological conditions, and future climate projections (temperature and precipitation) at 1- and 3-month time intervals; these variables are optimized for the original basin used to generate the model, but can be adjusted and customized based on the user's own watershed and location. The variables are used to generate a daily index value, which after being smoothed against a 30-day running average, can be used to evaluate whether current and projected water supply can meet demand, and if found insufficient, to prompt managers to begin aquifer recovery to meet water supply needs. By generating a daily numerical comparison of water supply and demand trends in light of climate projections, this index allows water managers to better evaluate how and when additional water supply sources may be needed, helping to maximize water system efficiency. This index can be used by utilities at various stages of water resources planning. For example, it can be used to inform and justify current aquifer management decisions, or can serve as a useful example for water systems that rely on multiple water sources or that are trying to develop a water supply decision framework.

Accessibility: Open access, needs adjustment to local basin
Tool Type: Decision Support
Water subsector: Water supply and storage
Water Resource Types: watersheds, rivers and streams, lakes and reservoirs
Sectors: Water resources, water utilities (drinking water, stormwater)
Intended Audience: Water utility managers, planners, engineers

Awareness | **Assessment** | Planning | **Implementation** | Integration | Evaluation | Sharing

Example in use: The ASR Recovery Initiation Index was originally developed by the Peace River Manasota Regional Water Supply Authority in Florida. During high flow periods, the Authority captures and stores water from the Peace River in several underground aquifers, in addition to two surface reservoirs. This stored water is used to for water supply during low-flow periods and/or during high tides, when the water at the Authority's river intake station is too brackish to pump. However, utilizing stored aquifer water presents many management challenges. For example, the water must be extensively treated, can cause algal blooms in surface reservoirs, and must be pumped at a rate that avoids depletion of underground reserves until the onset of the next wet season. To minimize operational costs and mitigate negative consequences of aquifer pumping, the Authority worked collaboratively with other partners to develop the ASR Recovery Initiation Index. The index functions as a decision support tool to help the Authority decide when to initiate aquifer recovery each season, helping prevent early withdrawals that can increase utility costs, water quality problems, and vulnerability to future water shortages.

BASINS CAT (Better Assessment Science Integrating Point & Non-Point Sources Climate Assessment Tool)

http://water.epa.gov/scitech/datait/models/basins/index.cfm

Developed By: EPA
Contact Information: basins@epa.gov

Description: BASINS was developed by the EPA to integrate environmental data, analysis tools, and watershed and water quality models to help inform watershed management and total maximum daily load (TMDL) development efforts. BASINS is a desktop application that utilizes GIS capabilities to compare how land use change and various management practices affect water quality. Through BASINS, users can access national and local data related to watersheds, and can apply assessment and planning tools and run nonpoint loading and water quality models. BASINS incorporates four types of data into simulation models: cartographic data showing administrative and hydrologic boundaries and road systems; environmental background data that includes information on soil characteristics, land use, and stream hydrography; monitoring data on water quality, streamflow, and groundwater; and point source data regarding discharge location, the type of facility, and estimated loading. BASINS also includes a number of environmental and utility assessment tools to help users evaluate water quality and pollution issues, identify data gaps and monitoring needs, and develop further watershed modeling tools.

BASINS CAT enhances the existing capability of BASINS by allowing users to assess how climate change may interact with land use and management changes to affect watersheds and water systems. Using BASINS CAT, users can simulate various climate change scenarios by adjusting historical temperature and precipitation data, allowing simulations of short- or long-term climate change, as well as evaluation of how variable seasonal or monthly conditions affect hydrological and water quality parameters. Users can also model impacts from increasing frequency of precipitation events. Regional, local, and state agencies can use BASINS CAT to perform climate-informed watershed and water quality modeling. Information from BASINS CAT can be used in watershed management, total maximum daily load (TMDL) development, coastal management, nonpoint source pollution programs, water quality monitoring, and National Pollutant Discharge Elimination System (NPDES) permitting, as well as to assess watershed sensitivity to climate change and to develop robust management strategies to help watersheds adapt to changing climate conditions.

Accessibility: Open access
Tool Type: Modeling, Decision Support
Water subsector: Water quality, water supply and storage, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Conservation/restoration, fisheries, land use planning, policy, rural/indigenous livelihoods, socioeconomic development, scientific research, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Land managers, natural resource managers, planners, engineers, scientists

Awareness | **Assessment** | **Planning** | Implementation | **Integration** | Evaluation | **Sharing**

Example in use: BASINS CAT has been applied to meet various watershed modeling needs across diverse regions of the United States. In the eastern United States, it has been used to create precipitation scenarios for use in conjunction with the Storm Water Management Model (SWMM), informing a stormwater runoff and mitigation assessment for an urban area along the Upper Roanoke River in Virginia. BASINS CAT was also used to analyze interactions between urbanization, climate change, and stormwater runoff volume and pollution in the Western Branch of the Patuxent River in Maryland. This particular study evaluated how shifts in precipitation volume, event intensity, and total impervious cover influenced stormwater runoff and pollutant loads. In the western United States, BASINS CAT has been used to analyze how water quality and flow in the Tualatin River in Oregon may change in response to altered precipitation regimes, and to analyze how streamflow may respond to shifts in the duration and magnitude of drought periods in California.

C-CAP Land Cover Atlas

http://coast.noaa.gov/digitalcoast/tools/lca

Developed By: NOAA Office for Coastal Management
Contact Information: ocm.lca@noaa.gov

Description: C-CAP Land Cover Atlas is an online data viewer that allows users to observe changes in regional land cover over a selected range of time between 1996 and 2011. The Atlas summarizes general trends (e.g., changes in forest cover, change in developed land), and lets users focus on specific changes they are interested in (e.g., changes in estuarine areas and marshlands). Users can also create summary reports and data tables that can be used to aid decision-making processes. The Atlas makes land cover data accessible to a variety of users by providing an online viewing platform that does not require the use of GIS or other software. The data and information used in the Land Cover Atlas are developed through NOAA's Coastal Change Analysis Program (C-CAP), which compiles standardized inventories of data derived from analysis of data from remotely sensed imagery related to changes in coastal intertidal areas, wetlands, and adjacent upland areas for the coastal United States.

Accessibility: Open access
Tool Type: Visualization, Modeling, Decision Support
Water subsector: Water delivery
Water Resource Types: Watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Agriculture, aquaculture, conservation/restoration, fisheries, forestry, infrastructure, land use planning, policy, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, engineers, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The C-CAP Land Cover Atlas has been applied in a variety of coastal states and regions, such as the Pacific Islands, the Gulf of Mexico, and the Delaware River Basin. For instance, in the Gulf of Mexico, the Ocean Conservancy used data from C-CAP Land Atlas Cover in the creation of a region-wide coastal and marine atlas (The Gulf of Mexico Ecosystem: A Coastal and Marine Atlas[1]), which contains multiple maps of various topics (e.g., oceanographic features, invertebrate and fish distribution, human uses) and can be used as a tool to help decision-makers plan restoration and management activities. In the Pacific Islands, NOAA's Pacific Islands Fisheries Science Center used data from the Land Atlas Cover to analyze changes in the amount of impervious surface, cultivated land, and pasture land throughout the Pacific Islands. This information was analyzed to see how changes in land cover were affecting runoff, informing planning efforts for a "ridge-to-reef" approach for watershed management.

CanVis

http://coast.noaa.gov/digitalcoast/tools/canvis?redirect=301ocm

Developed By: NOAA Office for Coastal Management and USDA National Agroforestry Center
Contact Information: Through website, http://coast.noaa.gov/contactform/

Description: CanVis is a visualization tool that displays the potential community impacts of coastal development and sea level rise through the creation of composite GIS maps and realistic landscape graphics that show potential changing conditions. Images created by CanVis can be used to communicate impacts to land managers, planners, and community members and to help managers and planners design strategies in response to potential changes. Users can identify a project and area that they would like to visualize and use CanVis to create comparative images. Users can load a base image (a photo of the area where they would like to see potential future changes) and alter the base photo by adding elements (e.g., additional docks, seawalls, changing sea levels), creating new images that show potential changes. While the tool does not evaluate environmental impacts, it provides a useful communication tool to help stakeholders see potential changes in coastal areas.

Accessibility: Open access
Tool Type: Visualization
Water subsector: Water delivery
Water Resource Types: Watersheds, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, fisheries, infrastructure, landscape architecture, land use planning, policy, socioeconomic development, scientific research, tourism/recreation, transportation, water resources,
Intended Audience: Land managers, natural resource managers, local authorities, planners, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: CanVis has been applied in coastal towns and regions throughout the United States. In the Southeast, the City of Myrtle Beach Planning Commission in South Carolina used CanVis to create comparative visualizations of the impacts of proposed land use changes. For example, CanVis was used to show how wetland buffers could increase overall wetland area, creating recreational birding and fishing opportunities and maintaining other critical services provided by wetland areas. City planners used these visualizations in planning commission meetings, resulting in the city council adding a new public park as a wetland buffer.

Climate Adaptation Knowledge Exchange (CAKE)

www.cakex.org

Developed by: EcoAdapt
Contact Information: info@cakex.org

Description: CAKE, a program of EcoAdapt, is a free online database focused exclusively on climate change adaptation. Users can query a variety of climate adaptation resources, tools, and case studies based on their topic or sector of interest, as well as interact with an active climate change adaptation community and browse a directory of climate change adaptation professionals. CAKE is a user-friendly resource that has applications for all individuals in all stages of adaptation. It can be used to gather basic information on how to start your adaptation journey, to access resources for use during adaptation development, implementation, and monitoring, and as a platform to share and communicate success stories and/or lessons learned. CAKE has developed customizable dashboards, which allows users to collect and house resources related to specific topics (e.g., climate-informed water resources management).

Accessibility: Open access
Tool Type: Portal, Communication/Outreach
Water Subsector: Water supply, water quality, water demand and use, water delivery
Water Resource Types: Rivers and streams, lakes and reservoirs, watersheds, groundwater, stormwater, wastewater, drinking water, marine, estuaries, wetlands
Sectors: Water resources, water utilities, land use planning, policy, disaster risk management, natural resources management (forestry, aquaculture, wildlife)
Intended Audience: Anyone interested in climate change adaptation

Awareness	Assessment	Planning	Implementation	Integration	Evaluation	Sharing

Example in use: EcoAdapt and the Greater Farallones National Marine Sanctuary in California used CAKE to generate lists and examples of potential climate change adaptation strategies for use in coastal and marine management. Stakeholders are using this information, as well as case studies provided by CAKE, to develop a suite of adaptation strategy recommendations for the National Marine Sanctuary and other regional management agencies to implement in the coming years. Sanctuary staff also used CAKE to document their vulnerability assessment and adaptation planning processes to facilitate similar activities in other marine sanctuaries throughout the United States.

Climate Change and Water: Resources and Tools Page

http://water.epa.gov/scitech/climatechange/Resources-and-Tools.cfm

Developed by: EPA
Contact Information: Office of Water Online Contact Form,
http://water.epa.gov/contactus.cfm

Description: The EPA's Climate Change and Water: Resources and Tools page provides information and links to various resources, data sources, and tools to facilitate climate-informed water management. Information is categorized into the following groups: infrastructure, watersheds and wetlands, coastal and ocean waters, water quality, tribal, climate change and water science and research, data and tools, and for kids and educators. Users can also link to other EPA sites where resources can be queried according to geographic region and/or more can be learned about federal collaborations dealing with climate change and water. Resources contained within the site represent and could be used for a diversity of adaptation phases and by a variety of audiences.

Accessibility: Open access
Tool Type: Portal
Water subsector: Water supply, water quality, water demand and use, water delivery
Water Resource Types: Watersheds, lakes and reservoirs, rivers and streams, wetlands, estuaries, marine, drinking water, stormwater, wastewater, groundwater
Sectors: Water resources, water utilities, infrastructure, education/outreach, public health, policy, landscape architecture, scientific research
Intended Audience: Water managers, water utility managers (drinking water, stormwater, wastewater), natural resource managers, policymakers, planners, local/state/regional authorities, scientists/researchers

Awareness | **Assessment** | **Planning** | Implementation | Integration | Evaluation | Sharing

Climate Change Resource Center

http://www.fs.usda.gov/ccrc

Developed By: USFS
Contact Information: ccrc@fs.fed.us

Description: The Climate Change Resource Center (CCRC) is a web-based, national resource that connects land managers and decision makers with useable science to address climate change in planning and application. The CCRC provides information about climate change impacts on forests and other ecosystems, and approaches to adaptation and mitigation in forests and grasslands. The website compiles and creates educational resources, climate change and carbon tools, video presentations, literature, and briefings on management-relevant topics, ranging from basic climate change information to details on specific management responses. Has a specific water resources page with synthesis of information, suggested reading, and links.

Accessibility: Open access
Tool Type: Portal
Water subsector: Water supply and storage, water quality, water delivery
Water Resource Types: Lakes and reservoirs, rivers and streams, watersheds
Sectors: Conservation/restoration, forestry, water resources
Intended Audience: Natural resource managers, land use planners, decision makers

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Climate Explorer

https://toolkit.climate.gov/tools/climate-explorer

Developed By: U.S. Climate Resilience Toolkit
Contact Information: noaa.toolkit@noaa.gov

Description: The Climate Explorer allows users to map and visualize how different climate-related stressors affect various communities, industries, and services. Users can zoom in to specific locations in the United States, using the Climate Explorer to model and visualize themes such as coastal flood risk, food resilience, ecosystem vulnerability, and the vulnerability of human health, water resources, tribal nations, transportation and supply chain, and energy supply and use. Within these themes, users simulate how major climate drivers, including sea level rise (1-3 m), current and past droughts, and flooding, are distributed on the landscape, and how they interact with different on-the-ground realities, such as population density, social vulnerability, land cover, and established infrastructure (e.g., roads, hospitals). Each of these components is mapped as an individual layer; overlapping layers allows users to investigate interactions between the various drivers and landscape characteristics, giving a clearer picture of vulnerability. Users can also create a permalink to their created maps; sharing this link with others allows individuals to access and view the same information, facilitating dispersed stakeholder engagement, education, and outreach. Users can also examine historical temperature and precipitation data for a given location. Information from the Climate Explorer can be used in a variety of planning efforts, as well as a method of communicating vulnerability to regional stakeholders.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water subsector: Water quality, water supply and storage, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, energy, environmental justice, fisheries, forestry, infrastructure, land use planning, policy, public health, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Climate Resilience Evaluation & Awareness Tool (CREAT)
http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm

Developed by: EPA
Contact Information: CRWUhelp@epa.gov

Description: The Climate Resilience Evaluation & Awareness Tool (CREAT) helps drinking water, stormwater, and wastewater utility managers analyze water utility risk in relation to climate change and explore potential adaptation strategies. CREAT is a free software tool and requires a Windows operating system, as well as other hardware and software requirements. Integrating downscaled information from recent national climate and climate impact assessments, various climate change scenarios, different customizable adaptation planning options (i.e. traditional risk assessment, scenario-based decision making), and libraries of typical water utility assets, CREAT facilitates personalized, region-based assessments of climate risk and adaptation opportunities for water utility managers. These assessments include risk analyses for both utility assets and utility operations, as well as analyses of risk at multiple locations, time scales, and under multiple climate scenarios. Risk reduction and cost reports generated through the CREAT assessment process can be integrated into long-term planning efforts, guide adaptation strategy development, help reduce the vulnerability of water utilities to climate and climate-driven changes, and be used by water utility managers to communicate climate risk and adaptation information to decision makers, stakeholders, and the public.

Accessibility: Open access
Tool Type: Modeling, Decision Support
Water Subsector: Water supply, water delivery
Water Resource Types: Drinking water, wastewater
Sectors: Water utilities, public health, planning, disaster risk management
Intended Audience: Water utility managers

Awareness | **Assessment** | **Planning** | Implementation | Integration | Evaluation | Sharing

Example in use: CREAT was used by the town of Manchester-by-the-Sea, located in Cape Ann, Massachusetts, to evaluate how different climate change scenarios could affect its wastewater treatment plant. Located less than 10 feet above sea level, this plant is vulnerable to flooding as a result of sea level rise, storm surge, high tides, and during extreme precipitation events. CREAT was also used to help analyze different management actions that could be taken to enhance the resilience of plant infrastructure to climate change impacts.

ClimateWizard

http://www.climatewizard.org/

Developed By: The Nature Conservancy (TNC), University of Washington, University of Southern Mississippi
Contact Information: General questions: climatewizard@tnc.org

Description: ClimateWizard is a web-based simulator developed collaboratively between The Nature Conservancy, the University of Washington, and the University of Southern Mississippi. ClimateWizard allows users to access and visualize climate change information and predict future climate change impacts for any given location worldwide. Users are able to select a state or country of interest and visualize changes in average temperature and precipitation that have occurred to date and to see projected changes through the end of the 21st century. Projected changes are based on the three different emission scenarios presented in the IPCC Fourth Assessment report, and users can select which emissions scenario they prefer to use. Users can also select from a variety of different General Circulation Models (GCMs), which simulate interactions of atmosphere, land, oceans, and ice. The ClimateWizard incorporates sixteen different GCMs from various institutions, such as the Max Planck Institute for Meteorology, the Hadley Center for Climate Prediction, and Research, and the National Oceanographic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory. In the web viewer, users can select an average of all the models, an ensemble of the lowest or highest models, ensembles of various in-between values, or select specific GCMs. Users can view data in the web portal or import data into ArcGIS. ClimateWizard can be used by the general public to better understand climate change trends, or by technical users looking to get more specific information to inform planning processes.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water Subsector: Water supply, water quality, water demand and use, water delivery
Water Resources Types: Rivers and streams, lakes and reservoirs, watersheds, groundwater, stormwater, wastewater, drinking water, marine, estuaries, wetlands
Sectors: Water resources, water utilities, land use planning, policy, disaster risk management, natural resources management (aquaculture, wildlife)
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: ClimateWizard has been applied in a number of projects to analyze potential climate impacts, design adaptation strategies, and evaluate potential management and restoration activities. For instance, the Appalachian Trail Conservancy used ClimateWizard to measure projected landscape changes along the Appalachian Trail to identify and quantify potential future threats to the trail.

Coastal Change Hazards Portal

http://marine.usgs.gov/coastalchangehazardsportal

Developed by: USGS
Contact Information: cch_help@usgs.gov

Description: The USGS Coastal Change Hazards Portal allows users to explore and interact with data, models, and tools related to three primary coastal hazard categories: severe storms, shoreline change, and sea level rise. The portal hosts an on online visualization tool for all three hazard categories, and users can download all source data, publications, and relevant resources for external use. In addition, users can group data and resources from different hazard areas to explore synergistic interactions of different coastal hazards. By providing post-storm analyses and scenario-based projections of storm impacts, documented changes and trends in shoreline change, and two separate sea level rise/shoreline change vulnerability analyses, the USGS Coastal Change Hazards Portal provides easily accessible, actionable information that can be used by decision-makers at a variety of levels to enhance adaptation, planning and preparedness activities in coastal regions.

Accessibility: Open access
Tool Type: Visualization
Water Subsector: Water delivery
Water Resource Types: Estuaries, wetlands, stormwater, drinking water
Sectors: Conservation/restoration, disaster risk management, emergency management/preparedness, land use planning
Intended Audience: Regional/state/local authorities, planners, policymakers, natural resource managers

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Coastal Community Resilience Index

http://masgc.org/assets/uploads/publications/662/coastal_community_resilience_index.pdf

Developed by: Mississippi-Alabama Sea Grant Consortium (MASGC), NOAA Coastal Storms Program, Gulf of Mexico Alliance Coastal Community Resilience Team
Contact Information: Tracie Sempier, Coastal Storms Outreach Coordinator, MASGC, tracie.sempier@usm.edu; Jody Thompson, Environmental Extension Associate, MASGC, jody.thompson@auburn.edu

Description: The Coastal Resilience Index (CRI) is a self-assessment tool, in worksheet form, that evaluates community storm preparedness and recovery potential. Designed for quick and easy use by community leaders, the CRI guides discussion and self-assessment of important coastal assets — including infrastructure and facilities, transportation, community plans, mitigation measures, business plans, and social systems — in relation to self-defined storm scenarios, facilitating identification of areas where community resilience could be bolstered. In addition to general storm resilience, the CRI includes many evaluations related to water resources, including the resilience of water utility infrastructure, floodplain management strategies, and developing alternative potable water sources. The CRI can inform resource allocation decisions and/or help with the prioritization of projects aimed at reducing coastal city storm vulnerability. The CRI is available for free download, depends mainly on the knowledge of local leaders, and is intended to be used frequently (e.g., annually, bi-annually) and/or re-assessed as rates of climate and climate-driven changes shift. The CRI also includes additional resources for communities looking to find more detailed information.

Accessibility: Open access
Tool Type: Decision Support
Water Subsector: Water quality, water delivery
Water Resource Types: Stormwater, drinking water, rivers and streams, marine
Sectors: Emergency management/preparedness, disaster risk management, policy, land use planning, public health, infrastructure, transportation, energy, water utilities
Intended Audience: Local authorities, local planners and policymakers, water utility managers

Awareness | **Assessment** | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The Gulf of Mexico Alliance worked with Orange Beach, Alabama, to complete an in-depth municipal vulnerability assessment using the Community Resilience Index and other vulnerability assessment tools. This assessment led to an update of the town's emergency management plan, enhancing the overall resilience of this coastal community to climate change impacts.

Coastal County Snapshots

http://coast.noaa.gov/digitalcoast/tools/snapshots

Developed By: NOAA Office for Coastal Management
Contact Information: coastal.info@noaa.gov

Description: Coastal County Snapshots is an online tool that produces user-friendly reports identifying and describing three categories of coastal hazards and change — flooding risk, wetland impacts, and ocean jobs impact — for selected coastal counties in the United States. Users select a coastal county, and the tool generates reports for the three categories identifying and describing changes that have occurred (e.g., changes in land cover, job trends) and important sectoral information (e.g., amount of coastal infrastructure at risk from flooding, how wetlands can be used to reduce flood impacts). Information generated in the snapshots can be used to help communities become more resilient to coastal hazards. The snapshots contain simple charts, graphs and descriptions of impacts and other relevant information, and are useful outreach and communication tools that can be used to educate decision-makers, managers, and coastal citizens.

Accessibility: Open access
Tool Type: Decision Support, Communications/Outreach
Water subsector: Water delivery
Water Resource Types: Watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, fisheries, infrastructure, landscape architecture, land use planning, policy, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, engineers, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The Coastal Snapshots tool has been applied throughout the United States. In the Southeast, the State of Florida integrated access to the Coastal County Snapshot tool in its Geospatial Assessment Tool for Operations and Response (GATOR), an interactive mapping tool used to assist emergency preparedness and responses. The Coastal County Snapshots tool was added to GATOR to provide additional demographic, economic, and environmental data to the interface. The tool helps emergency managers use the reports to assess a county's exposure to storms and flooding and helps managers communicate with coastal communities about coastal hazards and risks.

Coastal Flood Exposure Mapper

http://www.coast.noaa.gov/floodexposure/#/splash

Developed By: NOAA Office for Coastal Management
Contact Information: https://coast.noaa.gov/contactform

Description: The Coastal Flood Exposure Mapper helps communities understand their risks and vulnerability to coastal flooding. The mapper was first developed following Hurricane Sandy to provide a tool to show areas susceptible to coastal flooding, storm surge, and inundation, and to inform communities and local authorities about the risks their communities face. Users are able to explore maps that show how natural resources, communities, and infrastructure and development will be exposed to coastal flooding hazards. Users can select a given area (data is available for 20 states on the East Coast and Gulf of Mexico), and create maps depicting FEMA flood zones, and showing risks from shallow coastal flooding, storm surge, sea level rise, or an aggregate of these risks. The mapper incorporates data from NOAA's Sea Level Rise Viewer, but expands on the data presented there by showing risk and vulnerability for coastal hazards in addition to sea level rise.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water subsector: Water quality, water delivery
Water Resource Types: Watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, energy, engineering, infrastructure, landscape architecture, land use planning, policy, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Land managers, local authorities, planners, engineers, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Coastal Resilience

http://coastalresilience.org/

Developed By: The Nature Conservancy (TNC)
Contact Information: coastalresilience@tnc.org

Description: Coastal Resilience is a portal and mapping tool to assess vulnerability to coastal hazards and design strategies to reduce risk. The tool focuses on risk and vulnerability of coastal areas to current and future storms and sea level rise. Coastal Resilience also focuses on understanding how and under what conditions natural ecosystems can be used as part of strategies for increasing coastal protection. Using a web-based mapping function, users can generate maps for selected areas showing how habitats and ecosystems in the region will change given different sea level rise and storm scenarios, and can compare changes under different scenarios. The tool also uses various spatial model outputs to show different scenarios of how tidal marshes may change and advance with sea level rise and future storms. The mapping tool also has layers to show social vulnerability of local communities and overall risk, and also allows communities to input locally specific data that can be used to inform decisions and evaluate success of adaptation and restoration options. Users can also identify areas where nature-based and other types of adaptation options can be used to reduce risk, a feature that helps communities develop solutions to increase resilience. Coastal Resilience also serves as a portal to a variety of reports and other resources. For example, it links to reports that discuss what metrics can be used to ensure the success of adaptation and restoration solutions. Coastal Resilience can be used by a variety of practitioners in coastal areas to evaluate how climate change may affect ecosystems, communities, and water resources.

Accessibility: Open access
Tool Type: Visualization, Decision Support, Portal
Water Subsector: Water delivery
Water Resources Types: Rivers and streams, watersheds, marine, estuaries, wetlands
Sectors: Water resources, water utilities, land use planning, policy, disaster risk management, natural resources management (aquaculture, wildlife)
Intended Audience: Land managers, natural resource managers, planners, policymakers, scientists, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: Coastal Resilience has been applied in the Caribbean (USVI, Grenada, St. Vincent, and the Grenadines), Southeast Florida and the Florida Keys, the Gulf of Mexico, Connecticut, New Jersey, New York, North Carolina, California (Monterey Bay and Ventura County), and Washington. In Southeast Florida, TNC partnered with the Southeast Florida Regional Climate Change Compact to identify opportunities for nature-based approaches to increasing coastal resilience and protection, and evaluate potential future challenges and risks from climate change and design responses and solutions. In North Carolina, TNC partnered with multiple stakeholders in Roanoke Island and Englehard, two low-lying areas that are likely to be threatened by increased coastal storms and flooding, to map economic, social, and natural assets in the region, identify high-risk areas, and determine where restoration activities of ecosystems such as oyster reefs, marshes, and wetlands could be implemented.

Creating Resilient Water Utilities

https://www.epa.gov/crwu

Developed by: EPA
Contact Information: CRWUHelp@epa.gov

Description: The Creating Resilient Water Utilities (formerly the Climate Ready Water Utilities [CRWU]) Toolbox is an online compendium of climate-related information useful for water sector practitioners. Resources are categorized into one of the following groups: publications and reports; case studies; workshops; and adaptation strategies. Users can also browse region-specific resources through an interactive map, or query specific resources according to different types of water resources, climate change impacts, and/or responses. The database is updated frequently, and can be used by a variety of audiences in various stages of adaptation planning and implementation.

Accessibility: Open access
Tool Type: Portal
Water subsector: Water supply, water quality, water use and demand, water delivery
Water Resource Types: Drinking water, stormwater, wastewater, groundwater, lakes and reservoirs, rivers and streams, watersheds, wetlands, estuaries
Sectors: Water utilities, water resources, conservation/restoration, public health, policy
Intended Audience: Water utility managers (drinking water, stormwater, wastewater), natural resource managers, local/state/regional authorities

> ***Example in use***: Orange Water and Sewer Authority (OWASA) in North Carolina regularly uses CRWU to improve the resilience of their water provisioning, water reclamation, and stormwater services. Along with participating in regional conferences and meetings, CRWU has increased OWASA's exposure and access to cutting-edge and unique water management solutions in the face of climate change. OWASA is now applying many of the tools and resources available through CRWU, and is also involved with the continual expansion and updating of this online information portal.

Drought Impact Reporter

http://droughtreporter.unl.edu

Developed by: National Drought Mitigation Center
Contact Information: DIRinfo@unl.edu

Description: The Drought Impact Reporter is an online database that maps recorded drought impacts in the United States. The Drought Impact Reporter defines a drought impact as "an observable loss or change that occurred at a specific place or time because of drought." The reporter maps the number of drought-related impacts down to the county level, and provides critical information detailing type, location, and extent of drought impact, along with relevant source information. Impacts are broken down into the following categories: agriculture, energy, plants and wildlife, society and public health, water supply and quality, business and industry, fire, tourism and recreation, and relief, response and restrictions. Users can query more specific information by state, county, impact categories, time interval, cost, positive/negative impact, report source type, or through keywords, as well as submit their own impact report. In addition, drought impact information can be overlaid with other data sources, including the U.S. Drought Monitor, hydrologic unit codes, climate divisions, congressional districts, and risk management agency regions. Along with collecting impacts, the Drought Impact Reporter also collects and maps published regional reports, which may indicate the possibility of future drought impacts. For example, reports on county burn bans, water restrictions, and informational briefings from state and national agencies can be mapped as a unique layer to explore what areas may be expected to experience drought impacts in the near future. The Drought Impact Reporter can be used by many user groups and sectors to understand historical and ongoing drought conditions and impacts, which can be useful in adaptation planning efforts.

Accessibility: Open access
Tool Type: Monitoring, Visualization
Water subsector: Water supply, water quality
Water Resource Types: Drinking water, groundwater, lakes and reservoirs, rivers and streams
Sectors: Disaster risk management, water resources, agriculture, water utilities, tourism and recreation, public health, energy, wildlife, socioeconomic development, emergency management and preparedness, rural/indigenous livelihoods
Intended Audience: Local/state/regional authorities, water utility managers, natural resource managers, farmers, public, scientists

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Drought Management Database

http://drought.unl.edu/droughtmanagement/Home.aspx

Developed by: National Drought Mitigation Center
Contact Information: ndmc@unl.edu

Description: The Drought Management Database collects and provides examples of how different U.S. regions and sectors are responding to and mitigating drought. This online database can be useful for various levels of government looking to engage in drought preparedness and response planning, as well as for sectoral decision makers looking to undertake similar planning efforts, as it provides real-world examples and lessons learned. Users can quickly query drought strategies by sector and sub-sector, including: farming, livestock production, water supply and quality, energy, recreation and tourism, fire, plants and wildlife (environment), and society and public health. A more advanced search function also allows search customization according to sector/subsectors, publication date and type, scope (e.g., regional, county, tribal), geographic location, and activity type (e.g., pre-drought mitigation/adaptation, drought response, planning/policy, technical and financial assistance). Users can also submit their own tried and tested strategies.

Accessibility: Open access
Tool Type: Portal, Communication/Outreach
Water subsector: Water quality, water supply and storage, water demand/use, water delivery
Water Resource Types: Drinking water, watersheds, rivers and streams
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, engineering, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, public health, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, scientists, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Drought Risk Atlas

http://droughtatlas.unl.edu/

Developed by: National Drought Mitigation Center. Other contributors: High Plains Regional Climate Center, Applied Climate Information System, National Integrated Drought Information System, USDA Risk Management Agency

Contact Information: (402) 472–6707, droughtmonitor@unl.edu

Description: The Drought Risk Atlas is an online visualization tool that allows users to analyze and compare historical and contemporary droughts at the local level to better understand drought risk. The atlas allows users to explore past drought characteristics for specific geographic regions by compiling data from numerous monitoring stations; users can select a monitoring station within their area, as well as select other stations that exhibit similar precipitation patterns. The atlas also allows analyses of different time intervals, as it features compiled and combined data from a variety of different drought indices and monitoring records. This tool can help inform decision making both during and prior to a drought. For example, it can help decision makers increase their understanding of how current droughts compare to past drought events, providing critical information that can inform the allocation of resources. In addition, the Drought Risk Atlas can be used proactively to help develop drought management decision thresholds and/or to design more resilient drought response plans. The Drought Risk Atlas is likely a useful tool for a variety of sectors.

Accessibility: Open access
Tool Type: Monitoring, Visualization
Water subsector: Water supply
Water Resource Types: Lakes and reservoirs, rivers and streams, drinking water
Sectors: Conservation/restoration, wildlife, water resources, water utilities, disaster risk management, public health, agriculture, policy, emergency management and preparedness
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, scientists, farmers

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Extreme Water Levels

http://www.tidesandcurrents.noaa.gov/est/

Developed By: NOAA Center for Operational Oceanographic Products and Services
Contact Information: co-ops.userservices@noaa.gov

Description: Extreme Water Levels in an online product that allows users to analyze the likelihood that local tides will exceed a given elevation (mean high or low water) at different monthly and yearly time scales. Extreme Water Levels calculates these likelihoods based on over 30 years of monitoring data, and provides viewers with a rough idea of extreme tide heights expected every year, every other year, every 10 years, and every 100 years. Exceedance probabilities can be paired with real-time monitoring to document and determine extreme events, but can also be used for planning purposes to prepare for extreme low- or high-tide scenarios. Data is relevant only for specific NOAA CO-OPS monitoring stations, but a color-coded map allows general comparisons between different U.S. regions and sites.

Accessibility: Open access
Tool Type: Modeling, Monitoring
Water subsector: Water quality, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, engineering, fisheries, infrastructure, policy, public health, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists

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Federal Support Toolbox

http://watertoolbox.us/

Developed By: USACE
Contact Information: ada.benavides@usace.army.mil

Description: The Federal Support Toolbox is an online portal that connects and provides resources for individuals interested in or working on water resources issues in the United States and abroad. The toolbox is a useful resource for all phases of adaptation, as well as for visitors from different sectors. This toolbox facilitates both education and collaboration among the water resources community. For example, the toolbox provides access to water resources databases, models, tools, best practices, legislative and policy resources, and needs assessments, but users can also explore water-related outreach and education materials, communicate and engage with other practitioners in a variety of ways, and learn about and participate in various activities from local to global scales.

Accessibility: Open access
Tool Type: Portal, Communication/Outreach
Water subsector: Water quality, water supply and storage, water demand/use, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, engineering, environmental justice, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, public health, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Flood Inundation Mapper

http://water.usgs.gov/osw/flood_inundation/index.html

Developed By: USGS
Contact Information: mpeppler@usgs.gov

Description: The USGS Flood Inundation Mapper is an online flood mapping tool. Once a community develops a flood inundation map library through a collaborative effort with USGS, inundation maps are uploaded to the web-based mapper for broader viewing and access. Users can select a specific location and explore several different data sets, including current stream conditions, the estimated extent of historic flood events, and theoretical flooding scenarios. The current conditions data page gives a snapshot of current flood risk: it charts stream flow gauge height over the past four days, provides a prediction of stream gauge height over the upcoming 4 days, and identifies a flooding threshold at which agency "action" may be required. Users can also explore inundation patterns for historic flood events, or map theoretical inundation events by adjusting stream gauge height to model different flood levels. Spatial flooding extent for historic and theoretical events is mapped onto a user-decided base layer, with choices including topographical and street maps, allowing users to identify areas and assets that are vulnerable to different flood stages. The USGS mapper also provides and maps potential loss estimates for various flood scenarios. Users can analyze how building and vehicle loss changes with flood severity (as well as the spatial distribution of these losses), the amount and type of debris a flood may generate, and what sort of shelter requirements a city or county would need to provide to accommodate displaced citizens. Data from the mapper can be downloaded, and users can register for alerts for sites of interest. The USGS Flood Inundation Mapper can be used by various agencies and stakeholders to visualize and prepare for a variety of flood scenarios by identifying assets and areas most at risk. Information from the flood mapper can be integrated into a variety of planning efforts for both municipalities and natural resource managers.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water subsector: Water quality, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, engineering, environmental justice, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, public health, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Flood Inundation Maps

http://water.weather.gov/ahps/inundation.php

Developed By: National Weather Service
Contact Information: w-nws.webmaster@noaa.gov

Description: The NWS Flood Inundation Map is an online tool that identifies the extent and severity of flood risk for a given location. Users select from a variety of national river gauges to view flood risk at a specific location. For a given area, users can explore and map three different types of flood data: inundation, flood categories, and current flood forecast. The inundation mapper displays potential flood extent and depth; GIS-based shapefiles representing spatial flood coverage are overlaid on base maps of the user's choice, including topographical, street maps, or satellite images, and are shaded to represent various flood depths. The flood categories mapper can be used to explore the extent and depth of different flood categories, ranging from "below flood" to "major flood." Finally, visitors can use the current flood forecast mapper to identify and explore real-time flood risk. This last mapper will display inundation information only if the selected site is at imminent risk of flooding. Information generated by the Flood Inundation Map can inform local, state, and federal emergency and disaster management and planning during and prior to flood events; the information can also be used in a variety of other planning efforts to enhance flood resilience, such as land use planning, infrastructure design, and a variety of other planning activities. All data from the mapper can be downloaded for offline use and application.

Accessibility: Open access
Tool Type: Visualization
Water subsector: Water delivery
Water Resource Types: Stormwater, watersheds, rivers and streams
Sectors: Disaster risk management, emergency management/preparedness, engineering, infrastructure, land use planning, policy, public health, scientific research, transportation, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, public

Awareness | **Assessment** | **Planning** | Implementation | Integration | Evaluation | Sharing

Flood Resilience: A Basic Guide for Water and Wastewater Utilities

https://www.epa.gov/waterutilityresponse/flood-resilience-basic-guide-water-and-wastewater-utilities

Developed By: EPA
Contact Information: https://safewater.zendesk.com/hc/en-us/requests/new

Description: *Flood Resilience: A Basic Guide for Water and Wastewater Utilities* is an interactive PDF that can guide water utility managers through a flood risk reduction planning process. This digital resource, complete with worksheets, videos, and examples, takes managers through a four-step process to evaluate and enhance flood resilience of utility infrastructure and facilities. Steps include: identifying flood threats, evaluating vulnerable utility infrastructure and consequences of flooding, evaluating flood mitigation options, and developing a flood mitigation implementation plan. To enhance understanding of flood risk, the guide provides direction on interpreting FEMA flood maps, and helps managers link flood projections with their established infrastructure, evaluating the economic, operational, and public safety risks if various flood levels were experienced. With a better understanding of facility and infrastructure vulnerability, the guide then assists managers with exploring, developing, and prioritizing various flood mitigation options to reduce flood risk. Users can explore all options, or jump to mitigation strategies specifically for drinking water and wastewater systems. The guide also outlines how prioritized options can be integrated into an implementation plan with short-term and long-term planning horizons. This resource is intended primarily for water utility managers looking to enhance flood resilience and protect critical assets, but its general approach can be used by other groups to reduce flood risk (e.g., city planners).

Accessibility: Open access
Tool Type: Decision Support, Visualization
Water subsector: Water quality, water supply and storage, water delivery
Water Resource Types: Drinking water, wastewater
Sectors: Disaster risk management, emergency management/preparedness, energy, engineering, infrastructure, public health, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Water utility managers, local authorities, planners, engineers

Awareness | **Assessment** | **Planning** | Implementation | Integration | Evaluation | Sharing

Example in use: This guide was modeled after a successful flood mitigation pilot process undertaken by the EPA and the Water Department of Berwick, Maine. After flooding almost incapacitated Berwick's small water utility, the utility went through this four-stage process to better understand its flood risk, identify vulnerable infrastructure, and develop and implement various measures. The city has implemented several short-term solutions (e.g., sandbags, installing backflow preventers), and is integrating longer-term flood resilience strategies into a capital improvement program. These efforts are already paying dividends, as they helped minimize utility flood damage and operational shutdowns during a recent storm cycle.

Georgia Water Toolkit

https://www.gawatertoolkit.org

Developed By: Georgia Department of Community Affairs
Contact Information: Deatre Denion, Office of Environmental Management/GA Dept. of Community Affairs, deatre.denion@dca.ga.gov

Description: This web-based toolkit is designed to help local water managers understand and address water management challenges related to climate change, urban development, pollution, interstate water rights, and more. It highlights key issues as well as providing access to the most current regulatory, educational, and decision support information, as well as discussing funding opportunities. It was developed for the State of Georgia. The Georgia Water Toolkit is an online portal that provides links to a variety of information to assist local governments in addressing water resources management issues. Specific topics covered in the toolkit include: water supply and protection, water conservation and reuse, stormwater, wastewater, regional water planning, and funding. Connecting visitors with up-to-date regulatory, educational, and decision support resources, as well as providing general discussions and definitions of water management topics and relevant case studies, this toolkit is designed for use by both experienced professionals and local government staff who are just beginning to operate in the water resources management sector. This toolkit is targeted primarily for Georgia citizens, but many of the concepts and resources have cross-state applicability.

Accessibility: Open access
Tool Type: Portal
Water subsector: Water quality, water supply and storage, water delivery
Water Resource Types: Drinking water, watersheds, wetlands, rivers and streams, lakes and reservoirs**,** stormwater
Sectors: Land use planning, water resources, conservation/restoration, policy, forestry, disaster risk management, education/outreach, water utilities, infrastructure
Intended Audience: Local officials, local planners and policymakers, local water managers, local natural resource managers, educators

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

> ***Example in use***: The Douglasville-Douglas County Water and Sewer Authority shares several of its case studies on stormwater management and water reuse through the Toolkit.

Habitat Priority Planner

http://coast.noaa.gov/digitalcoast/tools/hpp

Developed By: NOAA Office for Coastal Management
Contact Information: csc@csc.noaa.gov

Description: The Habitat Priority Planner (HPP) is a downloadable tool that can be used in ArcGIS to analyze critical coastal habitat and help managers make decisions about conservation, restoration, and planning. The tool lets users inventory habitat and potential changes to habitat in a given study area, assess potential target habitat conditions, analyze different potential future scenarios (e.g., impacts of new development or restoration activities), and determine future planning decisions (e.g., best locations for development, coastal areas vulnerable to climate change). The HPP provides an interactive platform that is useful to use in a group decision-making setting; it allows users to create maps, reports, and data tables describing selected scenarios that can be used as communication tools in decision-making processes. Training for this tool is available, as it requires intermediate ArcGIS expertise.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water subsector: Water delivery
Water Resource Types: Watersheds, rivers and streams, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, socioeconomic development, scientific research, water resources, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, engineers, scientists

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The Habitat Priority Planner has been used in a number of coastal areas in the United States. For instance, in South Carolina, the Edisto Island Preservation Alliance (EIPA), a group of community members dedicated to preserving the historical, cultural, and natural heritage of their community, used the tool to evaluate target areas for conservation and to engage in participatory mapping exercises to get buy-in for plans to designate a National Scenic Byway. The HPP helped the EIPA eventually designate 50% of Edisto Island as conservation lands and successfully designate a National Scenic Byway.

i-Tree

General Tool: https://www.itreetools.org/
i-Tree Hydro: https://www.itreetools.org/hydro/index.php

Developed by: USFS
Contact Information: info@itreetools.org

Description: i-Tree, developed by the USFS, is a peer-reviewed software bundle that facilities maximizing benefits from urban forestry efforts. i-Tree provides a variety of analysis tools, including urban forest ecosystem services and aesthetics benefits analyses, planting scenario evaluations, and canopy cover analyses. One tool, i-Tree Hydro, which is currently available only in a beta version, is of particular relevance to water resources management. i-Tree Hydro allows users to explore how changes in tree cover and in the extent of impervious land cover (e.g., pavement) impact streamflow and water quality, conditions that are related to urbanization, runoff, and erosion and are responsive to changes in climate (e.g., precipitation changes). With integrated topographic information and hourly U.S. weather data, i-Tree Hydro users can generate localized and elevation-specific models and compare how different land cover scenarios affect local hydrology at both the county or city level, as well as evaluate how changes in management practices, combined with different precipitation intensities and volumes, affect flood risk and water quality. These models can be used to inform urban management, planning, and design efforts, to facilitate the development of best management practices, and to help address water quality issues and climate change resilience (e.g., minimize flood risk) in different U.S. cities and counties.

Accessibility: Open access
Tool Type: Modeling, Monitoring
Water Subsector: Water supply, water quality, water delivery
Water Resource Types: Rivers and streams, watersheds, groundwater, stormwater
Sectors: Forestry, land use planning, policy, water resources, natural resource management, disaster risk management, landscape architecture, public health
Intended Audience: Urban planners, urban foresters, local and county planners, policymakers, public

Awareness	**Assessment**	**Planning**	Implementation	Integration	Evaluation	Sharing

Example in use: Researchers at Mississippi State University are using i-Tree to help enhance community understanding of and engagement with urban forestry in Mississippi and Alabama. Urban forestry can help enhance city resilience by mitigating urban heat islands and slowing stormwater runoff, increasing water quality. Volunteer groups in various cities are using i-Tree and other monitoring systems to help collect baseline information about urban forest characteristics in their different communities. Researchers hope to use this information to inform the development of Urban Forest Plans, making each community more resilient to climate change impacts.

Inundation Analysis Tool

http://tidesandcurrents.noaa.gov/inundation/

Developed By: NOAA Center for Operational Oceanographic Products and Services
Contact Information: co-ops.userservices@noaa.gov

Description: The Inundation Analysis Tool is a web-based tool that analyzes how frequently and for how long high tide events have historically occurred, allowing users to better understand saltwater inundation and flooding trends for certain elevations and locations. Users select the site (must be a NOAA CO-OPS tide station), time period of interest, and the elevation for inundation pattern analysis (e.g., mean high water, mean tide level). The Inundation Analysis Tool generates a master table of tide events that have inundated the elevation of interest, as well as three different graphical representations to allow users to explore flooding patterns in more detail. Inundation frequency and duration patterns can be integrated into coastal planning efforts to increase the flood resilience of a variety of projects, such as marsh or aquatic system restoration, infrastructure projects, emergency and/or disaster management planning, land use planning, and other activities.

Accessibility: Open access
Tool Type: Modeling, Monitoring
Water subsector: Water quality, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, engineering, environmental justice, fisheries, infrastructure, landscape architecture, land use planning, policy, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: The Inundation Analysis Tool was used in a marsh restoration project at Fort McHenry in Baltimore, Maryland. Project partners used this tool to estimate how much time marsh vegetation spends submerged, which informed the suite of species planted as a part of the restoration effort. Planting species that can tolerate projected and recorded conditions helped make the marsh resilient to flooding damage and invasive species colonization, maintaining important ecosystem services and wildlife habitat.

Local Climate Analysis Tool (LCAT)

http://nws.weather.gov/lcat/

Developed by: NOAA, National Weather Service (NWS)
Contact Information: LCAT@noaa.gov

Description: The Local Climate Analysis Tool (LCAT) allows users to explore local climate variability in relation to global climate trends and to investigate the linkages between local climate, weather, and water events. Intended to enhance local climate expertise of National Weather Service (NWS) staff, LCAT analyzes available climate data sets (provided and recommended by NOAA) via the NWS Virtual Lab platform, helping users conduct local climate or correlation studies through a scientifically credible process. LCAT also provides avenues for scientific discussion and idea exchange; it allows users to query available studies, interact with other users, and upload study results for review and publication purposes. LCAT facilitates decision support in the realm of climate questions, and can be used as guidance in generating local climate studies and/or products. As an internal NOAA tool, LCAT is currently available for all NOAA users; non-NOAA users may use LCAT, but must have a NOAA-sponsored partner apply on their behalf to gain access to this tool.

Accessibility: Available to all NOAA users; non-NOAA users must have a NOAA-sponsored partner apply on their behalf
Tool Type: Modeling
Water Subsector: Water supply
Water Resource Types: Drinking water, stormwater, watersheds, lakes and reservoirs, rivers and streams
Sectors: Water resources, scientific research, disaster risk management
Intended Audience: National Weather Service Staff, NOAA Affiliates, Local weather forecasters, scientists, local planners

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Low Impact Development (LID) Atlas

http://www.clemson.edu/public/water/watershed/projects/lid.html

Developed By: National Nonpoint Education for Municipal Officials (NEMO) Network, South Carolina NEMO, South Carolina Sea Grant, California Clear, and Clemson University's Center for Watershed Excellence
Contact Information: Amy Scaroni, Carolina Clear Associate Coordinator, ascaron@clemson.edu

Description: The atlas serves as an information sharing tool for communities and organizations interested in implementing low-impact development projects and addressing stormwater and growth-related issues that impact water quality. The tool allows user to enter data regarding existing low-impact development projects. These projects are displayed on a regional map that shows existing projects and provides information about the project type (e.g., swale/bioswale, permeable pavement, water conservation), location, land use type, construction date, and links to additional information about the project. Although this atlas is focused on South Carolina, it contains project information for various states.

Accessibility: Open access
Tool Type: Communication/Outreach
Water Subsector: Water quality, water delivery
Water Resources Types: Watersheds, groundwater, stormwater, wastewater
Sectors: Water resources, water utilities, land use planning, policy
Intended Audience: Land managers, natural resource managers, planners, community members

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

> ***Example in use***: The Oak Terrace Preserve Project is a sustainable, green redevelopment effort in the City of North Charleston, South Carolina, featuring bioswales, rain gardens, permeable pavers, pocket parks, stormwater wetlands, and a tree preservation program that has retained 600+ trees on site. This project is one of several examples available on the LID Atlas.

National Aquatic Resources Surveys

http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm

Developed By: EPA
Contact Information: https://www.epa.gov/national-aquatic-resource-surveys/forms/national-aquatic-resource-surveys-contact-us

Description: The EPA, states, and tribes are conducting a series of surveys of the nation's aquatic resources. Often referred to as probability-based surveys, these studies provide nationally consistent and scientifically-defensible assessments of our nation's waters and can be used to track changes in condition over time. Each survey uses standardized field and lab methods and is designed to yield unbiased estimates of the condition of the whole water resource being studied. There are four surveys implemented on a rotating basis: National Coastal Condition Assessment, National Lakes Assessment, National Rivers and Streams Assessment, and National Wetland Condition Assessment.

Accessibility: Open access
Tool Type: Monitoring
Water subsector: Water supply and storage, water delivery
Water Resource Types: Lakes and reservoirs, rivers and streams, watersheds, wetlands
Sectors: Conservation/restoration, fisheries, water resources, wildlife
Intended Audience: Natural resource managers, water managers, State, regional, and local agencies

Awareness | **Assessment** | Planning | Implementation | Integration | **Evaluation** | Sharing

Example in use: The Albemarle-Pamlico National Estuary Partnership (APNEP) conducted a monitoring effort as part of the National Coastal Condition Assessment in 2015. Field sampling was conducted at 33 sites throughout the estuary to collect various water quality and sediment chemistry indicators (i.e. chlorophyll-a, dissolved oxygen, pH, metals, salinity, etc.). The results will be released in a forthcoming assessment.

National Stormwater Calculator

http://www2.epa.gov/water-research/national-stormwater-calculator

Developed By: EPA
Contact Information: SWC@EPA.gov

Description: The EPA Stormwater Calculator (SWC) is a desktop tool that can be used by individuals looking to reduce stormwater runoff at the local level. The SWC generates rainfall runoff volume and frequency estimates for any location in the United States or Puerto Rico using historic rainfall data, local soil properties, and land use cover inputs. Users can manipulate the land use category and evaluate how seven different green infrastructure methods can alter runoff volume and frequency on their property. This tool also has a specific climate change function that allows users to better understand how climatic variability and land use practices interact to affect stormwater runoff at local scales, which can inform future planning, policy, management, and implementation work in a variety of sectors, helping to mitigate flood risk and improve water quality.

Accessibility: Open access
Tool Type: Modeling
Water subsector: Water quality, water delivery
Water Resource Types: Stormwater
Sectors: Engineering, infrastructure, landscape architecture, land use planning, policy, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Land managers, water utility managers, local authorities, planners, policymakers, engineers, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: Students applied the National Stormwater Calculator to minimize stormwater runoff and create a resilient site design for a new community library in Mount Washington, Kentucky. Comparing original design plans with an updated plan that includes low-impact development (LID) components including cisterns, bioswales, and rain gardens, the students demonstrated that green infrastructure solutions could help mitigate five inches of stormwater runoff from the library site annually, as well as almost completely eliminate water needs at the facility itself. In addition, the students demonstrated that the LID components would help the site accommodate potential increases in precipitation as a result of climatic variability, minimizing flood risk for both the site and the larger community.

National Water Information System

http://waterdata.usgs.gov/nwis

Developed by: USGS
Contact Information: 1-888-ASK-USGS (1-888-275-8747), or submit a question through the website

Description: The USGS National Water Information System (NWIS) is an online water resources monitoring database that compiles site-based information on surface water, groundwater, water quality, and water use metrics. Within these categories, users can explore current conditions, historical trends, daily summaries, and field measurements, as well as conduct statistical analyses and examine other category-specific features (e.g., peak daily flows for surface water). Data housed on this platform are gathered from over 1.5 million USGS monitoring stations located in U.S. states and territories, and include information from rivers, streams, springs, lakes, reservoirs, ponds, wells, test holes, drains, excavations, and water facilities. The NWIS provides real-times access to conditions at many sites, as well as hosting historical records. Users can select sites for analysis by selecting them from a map or by using the Site Inventory System retrieval function to query sites based on a variety of attributes (e.g., latitude/longitude, altitude, state/territory, data type, etc.). Tutorials are available to facilitate use and understanding of water data and analysis tools housed on this website, and data is intended for use and examination by all individuals working with water resources.

Accessibility: Open access
Tool Type: Monitoring
Water Subsector: Water supply, water quality, water demand and use
Water Resource Types: Rivers and streams, lakes and reservoirs, groundwater, drinking water
Sectors: Water resources, engineering, water utilities, scientific research, public health
Intended Audience: Water managers, local/state/regional authorities, local/state/regional planners and policymakers, engineers, researchers, public

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

OpenNSPECT (Nonpoint Source Pollution and Erosion Comparison Tool)

http://coast.noaa.gov/digitalcoast/tools/opennspect

Developed by: NOAA Office for Coastal Management
Contact Information: coastal.info@noaa.gov

Description: OpenNSPECT estimates and maps how water quality (i.e. surface water runoff volume, pollutant loads and concentrations, and total sediment loads) may vary as a result of climate change, development, and other land use changes. OpenNSPECT integrates several different data types to generate maps of overland flow, pollutants, and erosion, including land use/land cover, elevation, soil types, rainfall factor, and precipitation. OpenNSPECT can be applied in a diversity of locales (i.e. coastal and non-coastal areas) and can be used by land managers, natural resource managers, local officials, planners, policymakers, and others as a comparative tool to inform planning processes and to help meet water quality objectives. For example, practitioners can compare tool outputs to national or state water quality standards, use the visual and numerical output components to identify best development options, or use outputs to guide the development of local watershed plans. OpenNSPECT can also be used to identify watershed areas that could be targeted for best management practices (BMP) development and pollution reduction activities. OpenNSPECT maps can also provide visual examples in proposals or presentations and/or be used as educational tools. Training is available for OpenNSPECT, and users can also register for and participate in an online community and user group where they can discuss real-time project applications of OpenNSPECT with other practitioners and access software updates.

Accessibility: Open access
Tool Type: Visualization
Water subsector: Water quality
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries, marine
Sectors: Conservation/restoration, land use planning, agriculture, water resources, public health, wildlife, policy, environmental justice, rural/indigenous livelihoods
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policy makers

Awareness | Assessment | Planning | Implementation | Integration | Evaluation | Sharing

Example in use: Weeks Bay National Estuarine Research Reserve (NERR) in Alabama used OpenNSPECT to assist with achieving water quality objectives outlined in its Watershed Management Plan. The estuary is exposed to significant nonpoint source pollution, particularly high fecal coliform. In combination with local water quality data, staff used N-SPECT to identify potential sources of fecal coliform contamination within the watersheds and to test how hypothetical management and land use changes would affect future fecal coliform levels. Using the data, they were able to implement a three-tier strategy to address nonpoint source pollution issues, which included natural resource-based planning, low-impact site design components (e.g., vegetation buffers), and implementation of best management practices in sub-watershed areas of highest pollution contribution.

Sea Level Affecting Marshes Model Visualization (SLAMM) View

http://www.slammview.org/

Developed By: Warren Pinnacle Consulting Inc., Image Matters LLC, and USFWS
Contact Information: USFWS: Brian Czech, Brian_Czech@fws.gov; SLAMM-View Application: Jeff Ehman, jeffe@imagemattersllc.com; SLAMM Simulator: Jonathan Clough, jclough@warrenpinnacle.com

Description: SLAMM-View was designed to improve comparisons of models produced through the SLAMM modeling tool (http://warrenpinnacle.com/prof/SLAMM). which simulates the effects of sea level rise (SLR) over the next century on ecosystem processes in marshes and coastal ecosystems and models predicted SLR impacts, shoreline modifications, and wetland conversions. SLAMM View also enables users to view predicted impacts to roads and assess the inundation frequency of roadways under different SLR scenarios. SLAMM View provides an additional tool to compare different geospatial outputs produced through the SLAMM model and let users compare model outputs from different years, or from one year under different SLR scenarios for selected project sites where the SLAMM model has been applied. The tool also provides a summary report detailing projected changes. Users can select from different SLR scenarios: the IPCC Scenario A1B Mean (39 cm of global average SLR); the IPCC Scenario A1B Maximum (69 cm of global average SLR); and global SLR ranges from 1-2 meters eustatic SLR.

Accessibility: Open access
Tool Type: Visualization, Modeling
Water subsector: Water delivery
Water Resource Types: Watersheds, wetlands, estuaries, marine
Sectors: Aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, fisheries, forestry, infrastructure, land use planning, policy, transportation, water resources, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, scientists

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Example in use: SLAMM View provides data for projects throughout the United States at both the regional and project site scale and serves as the public access point for SLAMM outputs. For example, the Gulf Coast Prairie Landscape Conservation Cooperative (GCPLCC) ran SLR simulations for the entire U.S. Gulf Coast to support a focal species analysis. Several parts of the coast had already been examined using SLAMM but the results were not directly comparable due to different sea-level scenarios and modeling approaches used. The GCPLCC funded a project to fill gaps in the geographic coverage of SLAMM and re-running previous simulations to generate consistent scenarios from 0.5-2 m of SLR by 2100 along the entire coast. The results were then used to assess the impacts of SLR on focal species and their associated critical habitats in support of the Gulf Coast Vulnerability Assessment Project. The final data is available on SLAMM-View (http://www.warrenpinnacle.com/prof/SLAMM/GCPLCC).

Sea Level Rise Viewer

http://coast.noaa.gov/digitalcoast/tools/slr

Developed By: NOAA Office for Coastal Management
Contact Information: coastal.info@noaa.gov

Description: The Sea Level Rise Viewer is an online simulator that show potential sea level rise and coastal flooding impacts for coastal areas in the United States and territories (with the exception of Alaska, due to the lack of sufficient statewide coastal elevation data) under different sea level rise scenarios. The viewer can be accessed via a computer or a mobile device. The user is able to select a sea level rise scenario ranging from one to six feet above the average highest tide level; the tool then shows coastal areas likely to be impacted by flooding under the selected scenario. The tool also has additional data, such as potential marsh impacts and marsh migration due to sea level rise, flood frequency, and predicted socioeconomic vulnerability for the affected areas. In addition to the maps, the tool provides textual explanations for each scenario explaining potential impacts. For certain locations, the tool contains images depicting sea level rise and flooding impacts, which can be used to see how various iconic landmarks are affected by sea level rise. The tool also offers links so that users can access more information about relevant issues, such as IPCC sea level rise projections, coastal sensitivity to sea level rise, and a social vulnerability index.

Accessibility: Open access
Tool Type: Visualization
Water subsector: Water delivery
Water Resource Types: Stormwater, watersheds, wetlands, estuaries, marine
Sectors: Conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, fisheries, infrastructure, land use planning, rural/indigenous livelihoods, scientific research, tourism/recreation, transportation, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists, community members

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Example in use: In Cape Canaveral, Florida, the viewer was used to create a map showing potential sea level rise impacts along the coast for a sea level rise scenario of 3 feet by 2100 and compare these changes to current coastal maps and an aerial image from 1958. The map highlights how sea level rise could impact important coastal development and infrastructure, as well as protected areas like the Merritt Island National Wildlife Refuge and the Canaveral National Seashore, which provide habitat for bald eagles, alligators, manatees, shore birds, and other species. Similarly, in South Carolina, the Sea Level Rise Viewer was applied to look at historical flooding trends in Charleston. Current data of areas that are vulnerable to coastal flooding were compared to city maps from 1863 and used to show that areas that currently vulnerable to flooding used to be creek and marsh lands that were filled in as the city expanded. This application demonstrates how data from the Sea Level Rise Viewer can be used to explain current flooding trends and predict future vulnerability to sea level rise.

Soil Climate Analysis Network (SCAN)

http://www.wcc.nrcs.usda.gov/scan/

Developed By: Natural Resources Conservation Service
Contact Information: tony.tolsdorf@por.usda.gov

Description: The Soil Climate Analysis Network (SCAN) is a network of monitoring sites established in agricultural and other areas across the United States. Soil moisture, soil temperature, precipitation, wind, and soil radiation data from these sites is collected, compiled, and presented via the online SCAN mapping tool. Using the mapping tool, users can access and explore real-time and recorded hydrological and climatological trends taking place in various areas of the county. Users can select specific sites of interest, or query sites by elevation, state, county, and available monitoring information. A vast amount of current and historic data is available for each site; along with SCAN data, many sites have SNOTEL, Snowcourse, water supply, and other climatological monitoring information, including air temperature, relative humidity, snow depth and snow-water equivalent, barometric pressure, reservoir storage, and streamflow. Users can explore hourly, daily, and water year trends, or link through to a monitoring site's specific page for more detailed information. SCAN data can be used by a variety of practitioners to inform water resources and natural resources management decisions, as it provides long-term monitoring information.

Accessibility: Open access
Tool Type: Monitoring
Water subsector: Water supply and storage
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, fisheries, forestry, land use planning, policy, scientific research, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers, engineers, scientists

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Storm Water Management Model Climate Adjustment Tool (SWMM-CAT)

http://www2.epa.gov/water-research/storm-water-management-model-swmm

Developed By: EPA and CDM, Inc.
Contact Information: tryby.michael@epa.gov

Description: SWMM-CAT allows users to evaluate climate change impacts on stormwater runoff volume and quality, and to explore how the application of various low-impact development (LID) options can be used to alter these hydrological parameters. SWMM provides a spatial and temporal analysis of runoff quality and quantity by dividing basins into multiple sub-catchment areas and analyzing runoff at different time steps. It covers a variety of different drivers that can cause runoff in urban areas, including rainfall, snowmelt, and groundwater percolation, among others, and also allows for mapping and modeling of different sub-catchment drainage system components, including pipes, channels, diversion structures, storage and treatment facilities, and natural channels. These components allow users to examine relationships between total rainfall, runoff, and various routing options at a sub-catchment scale to effectively plan and design stormwater and sewer systems. SWMM also allows users to integrate seven different LID options to explore how LID projects could be used to mitigate stormwater impacts and sewer overflows. These LID options include: permeable pavement, rain gardens, green roofs, street planters, rain barrels, infiltration trenches, and vegetated swales. On top of these standard SWMM functions, the add-in tool SWMM-CAT can be used to evaluate how changes in precipitation, air temperature, and evaporation may affect runoff trends. Users can manually adjust climate factors on a monthly time scale, or use a set of location-specific adjustments generated by the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3), which was used to generate downscaled climate information for the IPCC's recent report. SWMM-CAT can be used by a variety of practitioners looking to explore vulnerability and management and design options for stormwater systems, combined and sanitary sewers, and other urban drainage challenges in the face of climate change. It can also be used by non-urban entities.

Accessibility: Open access
Tool Type: Modeling
Water subsector: Water quality, water delivery
Water Resource Types: Stormwater, watersheds
Sectors: Conservation/restoration, disaster risk management, engineering, infrastructure, landscape architecture, land use planning, policy, public health, scientific research, water resources, water utilities (drinking water, wastewater, stormwater)
Intended Audience: Land managers, water utility managers, local authorities, planners, policymakers, engineers, scientists

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Surging Seas

http://sealevel.climatecentral.org/

Developed By: Climate Central
Contact Information: Heather Pittman, hpittman@climatecentral.org

Description: Surging Seas is an online repository of tools and resources that allows users to better understand coastal flood risk. Users can gain a basic understanding of flood risk in coastal areas, explore potential responses, and engage with a variety of mapping tools. After selecting a given coastal location in the United States, users can create maps showing areas vulnerable to flooding from sea level rise, storm surge, and tides, as well as map long-term submersion from sea level rise. The maps use data from NOAA and overlay this with coastal community features, such as points of interest, population density, and property values. Surging Seas also provides a "Risk Finder" tool that highlights local estimates of sea level rise and coastal flooding exposure for all coastal zip codes and municipalities, combining data on demographic, economic, infrastructure, and environmental variables for each community. The maps produced through Surging Seas show water levels changes, social vulnerability estimates, per capita income, direct risk areas, isolated areas, dry areas, and levees. Surging Seas also lets users compare the exposure of counties in a given location by different types of exposure (e.g., population, property, hospitals). Users can view maps showing comparative vulnerability, or they can produce brief analytic reports describing predicted changes and including simple figures and tables highlighting coastal hazard impacts. This information can be used in planning efforts and/or to communicate risk with the general public. Individuals can also submit case studies to Surging Seas, documenting their experience with coastal flooding impacts and community response.

Accessibility: Open access
Tool Type: Visualization, Modeling, Communications/Outreach
Water subsector: Water delivery
Water Resource Types: Watersheds, rivers and streams, wetlands, estuaries, marine
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, education/outreach, emergency management/preparedness, energy, engineering, fisheries, forestry, infrastructure, landscape architecture, land use planning, policy, rural/indigenous livelihoods, socioeconomic development, scientific research, tourism/recreation, transportation, water resources, wildlife
Intended Audience: Land managers, natural resource managers, local authorities, planners, engineers, scientists, community members

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Example in use: Surging Seas is used by the South Carolina Small Business Chamber of Commerce in its Sea Level Rise Education Project (www.SCBARS.org) to help communicate the threats posed by sea level rise to coastal tourism.

Template for Assessing Climate Change Impacts and Management Options (TACCIMO)

http://www.taccimo.sgcp.ncsu.edu/

Developed by: USFS (Eastern Forest Environmental Threat Assessment Center, Western Wildland Environmental Threat Assessment Center, Regional Forest Planning Units)
Contact Information: General Questions (Eastern US): Steve McNulty, smcnulty@fs.fed.us; General Questions (Western US): Nancy Grulke, ngrulke@fs.fed.us; Other Questions and Scheduling Training Sessions: Emrys Treasure, etreasure@fs.fed.us

Description: TACCIMO is an online tool that connects users to relevant climate and management information and data to facilitate climate-informed management of natural resources. It has a variety of features that allow a customizable user experience, including a literature search and review function, a downscaled geospatial climate modeling and mapping function, and a report generation function. These features can be used in combination or separately to gain a better understanding of climate projections and potential climate impacts on natural resources, and/or to inform decision-making, generate technical reports, and integrate climate information into current plans and management strategies. TACCIMO has higher levels of functionality for USFS employees, but is also useful for any land manager, researcher, or public individual interested in learning more about the implications of climate change for natural resources and exploring potential management options. In addition, the website houses case studies of successful TACCIMO applications, and provides links to other useful modeling tools and resources.

Accessibility: Open access, but with higher functionality for USFS employees
Tool Type: Portal, Communication/Outreach
Water Subsector: Water supply, water quality, water delivery
Water Resource Types: Watersheds, rivers and streams, lakes and reservoirs, groundwater, drinking water
Sectors: Water resources, forestry, conservation/restoration, education/outreach, scientific research, policy
Intended Audience: Federal, state, and private land managers, researchers, public, policymakers, natural resource managers

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Example in use: EcoAdapt used TACCIMO to inform climate change vulnerability assessments and adaptation planning efforts on Forest Service lands across the western United States. EcoAdapt helped USFS employees in California, Montana, Idaho, and Alaska better understand how climate change may impact habitats, species, and ecosystem services, and how to integrate climate change considerations into management protocols, operations, and planning efforts. This includes specific efforts related to aquatic habitats, species, and water-based recreation. This information has been used at project and planning levels, as well as to inform Forest Plan revisions, contributing to resilient resource management in the face of climate change.

Tidal Flooding

http://coast.noaa.gov/tidalfloodingvis

Developed By: NOAA Office for Coastal Management
Contact information: coastal.info@noaa.gov

Description: Tidal Flooding is an educational, online, narrated presentation provided by the NOAA Office for Coastal Management that describes tidal flooding and the risks communities may face with increased tidal flooding from heavy rains, sea level rise, and continued coastal development. The presentation outlines the formation of extreme high tides, potential impacts of extreme high tides, and how flooding will change with sea level rise. The presentation also describes five potential adaptation strategies that communities can use to prepare and increase resilience to tidal flooding (stabilizing the shoreline to protect coastal assets, realigning roads and creating green space, relocating and restoring buildings, improving tidal flow to marshes, and raising roads). For each of the strategies, the presentation offers a brief description and example, as well as a link for users to visit if they would like to see more information about the examples provided. The presentation also links to various other resources if viewers would like to learn more about flooding data, impacts, and response strategies.

Accessibility: Open access
Tool Type: Communications/Outreach
Water subsector: Water delivery
Water Resource Types: Watersheds, wetlands, estuaries, marine
Sectors: Education/outreach
Intended Audience: Land managers, local authorities, planners, community members

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U.S. Drought Portal

http://www.drought.gov/drought/

Developed by: NOAA via the National Integrated Drought Information System (NIDIS) Program Office
Contact Information: Online Contact Form, http://www.drought.gov/drought/contact

Description: The U.S. Drought Portal is an online portal that connects users to a variety of drought-, hydrological-, climate- and climate impact-related tools, products, regional programs, and resources. User-friendly and accessible products include current drought and climate monitoring platforms (e.g., the U.S. Drought Monitor), drought impact reporting and monitoring databases (e.g., the Drought Impacts Reporter), and forecasts related to drought and other climatological conditions. Users can investigate regional or state-level drought conditions, topic discussions, programs, and resources, and/or access a variety of tools that can be used to assess and plan for drought conditions, such as the Drought Management Database, which houses drought preparation, mitigation, and response strategies being employed across the country. The variety of information accessible through the U.S. Drought Portal can most likely be used by a variety of different sectors and in a variety of different adaptation applications.

Accessibility: Open access
Tool Type: Portal
Water subsector: Water supply, water quality
Water Resource Types: Drinking water, groundwater, rivers and streams, lakes and reservoirs
Sectors: Water resources, water utilities, agriculture, public health, policy, disaster risk management, emergency management and preparedness, tourism and recreation
Intended Audience: Natural resource managers, water utility managers, planners, policymakers, local/state/regional authorities, farmers, scientists

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Water Conservation Tracking Tool

http://www.allianceforwaterefficiency.org/Tracking-Tool.aspx

Developed by: Alliance for Water Efficiency
Contact Information: Jeffery Hughes, Administrative Director, jeffrey@a4we.org

Description: The Alliance for Water Efficiency (AWE) Water Conservation Tracking Tool is a program that allows water utilities to analyze various water conservation strategies and design conservation programs to maximize water savings and benefits while minimizing costs. The tool operates through Microsoft Excel and integrates real data from individual water utilities, allowing personalized and standardized analyses of water savings, costs, and benefits in two different units (i.e. English and metric). Water utility managers can design custom water conservation programs by selecting (up to 50) described and integrated conservation strategies. Further, the tool allows for both comparative planning exercises and real-time monitoring of water use, cost, and benefit changes after the implementation of conservation strategies. The AWE Water Conservation Tracking Tool is free for AWE members, and comes in three versions depending on the plumbing code and appliance standards of a user's state. Current versions include California/Texas, Georgia, and the Standard Edition (includes all states except California, Texas, and Georgia). Users also receive a detailed User Guide and one free hour of technical support from AWE staff.

Accessibility: Must be AWE member in good standing
Tool Type: Modeling, Decision Support, Monitoring
Water Subsector: Water demand and use
Water Resource Types: Drinking water
Sectors: Water utilities
Intended Audience: Water utility managers

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EPA Water Erosion Prediction Project Climate Assessment Tool (WEPPCAT)

http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=153583#Download

Developed by: EPA Global Change Research Program and USDA-ARS Southwest Watershed Research Center

Contact Information: Thomas Johnson, johnson.thomas@epa.gov

Description: WEPPCAT is a free, online erosion simulation tool that allows users to analyze potential stream sediment loading in response to various climate change and land management scenarios. WEPPCAT leverages the existing USDA Water Erosion Prediction Project (WEPP) Model, but has additional features that allow analysis of climate impacts and various land management practices on soil yield and loss. This tool allows for high user customization; users select their location (e.g., state, nearest climate station, soil type) and field characteristics (e.g., length, width, slope angle and shape, crop or management type), and can manipulate land management components to simulate adaptive management. For example, users can compare various agricultural land management techniques (e.g., till, mulch, chisel) and compare the benefits of various field buffers that vary in composition and width. WEPPCAT also allows high flexibility in future climate modeling. Users can adjust temperatures, mean precipitation and number of wet days per month, and examine impacts at varying elevations, latitudes, and longitudes. Further, WEPPCAT is one of the only simulation tools that allows users to manipulate and examine soil erosion impacts from increasing rainfall intensity. Users typically generate baseline conditions and assess the sensitivity of current practices to climate change, and then analyze how sediment yields shift under various climate change and management strategy scenarios. Results can be analyzed singularly or in comparison to numerous simulations, and all resultant and input data sets can be saved and accessed later for further analysis. Overall, WEPPCAT can be used to assess the sensitivity of different land parcels and adjacent water bodies to rain-based erosion under future climate scenarios, but can also be used to inform the development of sediment-focused best management practices that protect and/or enhance water quality.

Accessibility: Open access
Tool Type: Modeling
Water Subsector: Water quality
Water Resource Types: Watersheds, rivers and streams, stormwater
Sectors: Agriculture, forestry, land use planning, conservation/restoration, water resources (stormwater, drinking water)
Intended Audience: Farmers, foresters, land managers, regional/state/local agencies, planners, natural resource managers, water resources managers (stormwater, drinking water)

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Water Evaluation and Planning System (WEAP)

http://www.weap21.org/index.asp?action=200

Developed By: Stockholm Environment Institute U.S. Center
Contact Information: info@weap21.org

Description: The Water Evaluation and Planning (WEAP) System is a software tool designed to help users with integrated water resources planning. WEAP uses a GIS-based interactive platform to allow high user customization, and helps users generate, integrate, and analyze watershed-specific information related to water supply, demand, and quality, as well as ecological information. This information can be used as a quick snapshot of water supply and demand trends, but can also be run through a scenario generation tool, a policy analysis tool, and a financial analysis module to analyze how future potential changes could affect water quality, supply, and demand and costs of various water-related projects. For example, WEAP has a built-in capability to model shifts in rainfall runoff and infiltration, evapotranspiration, surface water/groundwater interaction, and instream water quality. Users can examine how climate shifts pair with shifts in policy, water infrastructure (e.g., reservoirs, desalination plants, wastewater treatment plants), and other factors to affect water resources in their study area. WEAP's integrative and highly customizable process facilitates informed decision making by allowing users to compare a variety of scenarios and examine water relationships from a variety of perspectives and scales. Users can also share WEAP-generated information in a variety of formats (graphical, tabular, and map-based), facilitating effective and clear communication with relevant stakeholders.

Accessibility: Open access
Tool Type: Modeling, Decision Support
Water subsector: Water quality, water supply and storage, water demand/use, water delivery
Water Resource Types: Drinking water, stormwater, watersheds, rivers and streams, lakes and reservoirs, wetlands, estuaries
Sectors: Agriculture, aquaculture, conservation/restoration, disaster risk management, emergency management/preparedness, environmental justice, fisheries, forestry, infrastructure, land use planning, policy, water resources, water utilities (drinking water, wastewater, stormwater), wildlife
Intended Audience: Land managers, water utility managers, natural resource managers, local authorities, planners, policymakers

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Example in use: WEAP was used to model the Apalachicola-Chattahoochee-Flint River Basin, which supplies groundwater and surface water to the states of Alabama, Georgia, and Florida. Facing increasing water use conflicts, these states used WEAP to evaluate water use and allocation scenarios, as well as to better understand current supply and demand trends. WEAP ultimately helped these states, along with federal and local partners, to create equitable and resilient water allocation agreements.

Water Supply Stress Index (WaSSI) Ecosystem Services Model

http://www.wassiweb.sgcp.ncsu.edu/

Developed by: USFS (Eastern Forest Environmental Threat Assessment Center & International Programs), Praecipio Consulting, Photo Science, Inc.
Contact Information: Model Functionality and Use: Peter Caldwell, pcaldwell02@fs.fed.us; Technical Issues: Erika Cohen, eccohen@fs.fed.us; Jennifer Moore Myers, jmooremyers@fs.fed.us

Description: The Water Supply Stress Index (WaSSI) Ecosystem Services Model is an online tool that models potential impacts of climate change, land use change and water consumption alteration (i.e. population growth and water withdrawals) on flow volumes, water supply stress, and ecosystem productivity. The WaSSI Ecosystem Services Model can be used technically to model impacts in the United States, Mexico, Rwanda, and Burundi, but can also serve as an educational tool to demonstrate linkages between water use, climate change, water availability, and carbon storage. The WaSSI Model allows for high levels of customization and interaction. Users can define model areas (by country), explore technical simulation input data, define various climate projections, time scales, land use changes, and water use changes for simulation analysis, and view and download simulation results. Both input data and output data can be viewed numerically, graphically, and spatially, and downloaded for later use. The WaSSI Model allows comparative analyses of different scenarios, which can be useful when looking at management tradeoffs related to ecosystem services (i.e. water yield and carbon sequestration), as well as during planning and adaptation efforts. For optimum use of the WaSSI Model, modelers suggest using Mozilla Firefox or Internet Explorer 8 and higher.

Accessibility: Open access
Tool Type: Modeling, Visualization
Water Subsector: Water supply, water demand and use, water delivery
Water Resource Types: Rivers and streams, groundwater
Sectors: Water resources, education/outreach, fisheries, scientific research
Intended Audience: Natural resource managers, researchers, educators, public, local/state/regional planners and policymakers

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> ***Example in use***: The WaSSI Ecosystem Services Model was used by the USFS in the Southern Forest Futures Project, which characterized major drivers for forest health and change across 13 southeastern states. The WaSSI model was used to examine how water stress, streamflow changes, and water supply may change under different climate and land use scenarios, helping to inform sustainable and resilient forest management.

Watershed Central, Handbook for Developing Watershed Plans to Restore and Protect our Waters, and Watershed Plan Builder

http://water.epa.gov/type/watersheds/datait/watershedcentral/index.cfm (Central Homepage)
https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/handbook-developing-watershed-plans-restore-and-protect (Handbook Page)
http://java.epa.gov/wsplanner/# (Watershed Plan Builder)

Developed by: EPA
Contact Information: Contact form through website

Description: Watershed Central, run by the EPA, is an online portal that houses a large variety of information related to watershed management. Useful for regional, state, and local officials as well as the public, Watershed Central provides links to resources, tools, data, guidance, funding recommendations, training opportunities, and online support communities focused on developing and implementing comprehensive watershed management plans. Two key components of Watershed Central include the *Handbook for Developing Watershed Plans to Restore and Protect our Waters* and the companion online Watershed Plan Builder. The Handbook, available for free download in PDF form, outlines watershed planning processes and provides guidance for watershed plan development efforts at numerous levels (e.g., communities, local/state/tribal/federal agencies), and includes particular detail on developing plans for impaired or threatened watersheds. The Watershed Plan Builder, an ESRI-powered interactive online tool built to accompany the Handbook, helps users develop a customized watershed plan outline with integrated mapping components. The Watershed Plan Builder gathers a variety of user- and watershed-specific information (including drivers for creating a watershed plan, regulatory watershed requirements, watershed activities, water and air quality concerns, land/habitat considerations, and stakeholder information) to form a customized watershed management plan outline. The Builder also allows users to interact with and integrate different mapping outputs, such as maps of different layers related to water quality, facility locations, and watershed boundaries, into their plan outline, providing a visual companion to the outline text. The Watershed Plan Builder is free and projects can be saved for later viewing and/or alteration.

Accessibility: Open access
Tool Type: Portal, Decision Support
Water Subsector: Water supply, water quality, water delivery
Water Resource Types: Watersheds, rivers and streams
Sectors: Water resources, conservation/restoration, public health, policy
Intended Audience: Local/state/regional/tribal authorities, planners and policymakers, natural resource managers, public, public health officials

Awareness | Assessment | **Planning** | Implementation | Integration | Evaluation | Sharing

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