5 — Key Infrastructure

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5 Key Infrastructure

Introduction

A society cannot function without well-maintained infrastructure that provides critical services for its citizens. These services include providing habitable residential and workspace, transportation, energy sources, telecommunications, clean water, health, and safety, as well as systems to control such infrastructure threats as flooding, and improper release or disposal of wastewater, solid waste, and hazardous materials.

Since the Industrial Revolution, significant infrastructure development in Massachusetts has occurred along the coastline, major rivers, and in floodplains. This trend, along with other urban growth patterns, placed much of Massachusetts' key infrastructure resources in areas that are predicted to experience adverse effects from climate change.

A compounding factor is that most, if not all, of the key infrastructure resources were sited and designed based on historic weather, sea level, and flooding patterns. Climate change impacts are predicted to result in significant changes to these variables, making many infrastructure assets in Massachusetts vulnerable to future damage. It is expected that increased frequency of extreme weather events, combined with sea level rise, will considerably raise the risk of damage to transportation systems, energy-related facilities, communication systems, a wide range of structures and buildings, solid and hazardous waste facilities, and water supply and wastewater management systems. Consequential changes in precipitation patterns, particularly from extreme weather events, will threaten key infrastructure assets with flood and water damage.

The seven main infrastructure sectors analyzed in this chapter are listed in Table 4.

Overview of Vulnerabilities

Predicted climate change impacts have the potential to damage or destroy key infrastructure throughout Massachusetts. A problem common to infrastructure design is that planners, engineers, and designers traditionally have used historic weather characteristics to determine the weather conditions that infrastructure assets can withstand. Since future climate patterns are expected to be different, designs based on historic weather patterns could leave infrastructure at risk.

Predicted climate change impacts—in particular, sea level rise and more numerous extreme storm events—have the potential to impair public and private services and business operations. A substantial rise in sea level, even during calm weather, will cause flooding of buildings, roadways, tunnels, water and wastewater treatment facilities, and equipment and instruments associated with power stations and telecommunication facilities. Solid waste landfills and hazardous waste sites located in low lying coastal areas also will be vulnerable. In addition, saltwater intrusion into freshwater aquifers located near the

SECTOR	INFRASTRUCTURE INVOLVED
Energy (electric, gas, petroleum)	Production, transmission, storage, and distribution including power plants, substations, electric lines, natural gas systems, and fuel systems
Transportation (land, sea, air)	Roads, highways, bridges, tunnels, subway, commuter and commercial rail, ferries, buses, airports, and ports
Water (supply, wastewater, stormwater)	Water sources, pump stations, storage tanks or reservoirs, distribution systems, drinking water treatment, municipal separate storm sewer systems, combined wastewater and stormwater systems, decentralized stormwater management systems, and septic systems
Dam Safety and Flood Control	Dams, dikes, and land levees
Solid and Hazardous Waste	Solid waste facilities and hazardous waste storage and management facilities
Built Infrastructure and Buildings	Commercial, residential, industrial, institutional, and governmental buildings
Telecommunications	Phone, internet, and cable

Table 4. ***Key infrastructure sectors vulnerable to climate change impacts***

coastline will compromise coastal drinking water sources.

Sea level rise will expose infrastructure to storm surges and shift the current 100-year coastal storm floodplain and velocity zone landward to cover much of the Back Bay and Boston waterfront areas, for example. Some of the state’s most significant infrastructure—including the Massachusetts Port Authority’s Logan International Airport and port/ maritime facilities, the Massachusetts Water Resources Authority’s (MWRA) Deer Island Sewage Treatment Plant, and highway and public transit tunnels—are located in these areas.

The expected increases in intensity and frequency of extreme storm events could severely impact infrastructure, damage public and private services, and negatively impact business operations throughout the state. High winds and flooding along rivers and streams have incapacitated both inland and coastal communities during large storm events such as the Blizzard of ’78, the Mother’s Day Storm of 2006, the Ice Storm of December 2008, and to some extent the recent Tropical Storm Irene (2011). In the past, such storms have been relatively infrequent and services have been restored relatively quickly. Occasionally much larger storms, such as the Hurricane of 1938, Hurricane Carol (1953), and Hurricane Donna (1960), have caused extensive devastation throughout Massachusetts. With more frequent large storm events, damage to key infrastructure could become more frequent, take longer to repair, and entail more costly repairs and economic disruption.

General Strategies

Preparing for future climate change impacts will take a coordinated effort of private and public sectors, non-profit organizations, and managers and users of infrastructure resources. Primary strategies should promote actions that will bolster infrastructure resources to defend them against these impacts while simultaneously supporting other sectors’ strategies,and promoting due diligence and sound management decision-making. These include:

1. Accurate Mapping and Surveys: Update floodplain mapping using new LiDAR elevation surveys and climate models to identify at-risk facilities and natural features, and establish action priorities with cost estimates. Conduct comprehensive LiDAR mapping of the Massachusetts coast, shoreline waterways, and other flood-prone land areas and facilities, complemented by a detailed three-dimensional survey of individual at-risk facilities to determine vulnerabilities, most cost-effective strategies (defend or retreat), and action time frames.

2. No Regrets Actions: These measures will bolster infrastructure resources for future climate change impacts and improve other related efforts. They could also be actions that reduce greenhouse gas emissions and save future investments and valuable resources. Examples include:

•conservation, efficiencies, and reuse of key resources, such as drinking water conservation and improved stormwater management, which will provide capacity and resilience for many key infrastructures to withstand climate change impacts;

- cost-effective and simple improvements, such as flood-proofing structures, which can be made during routine maintenance and upgrading.

3. Explore Possible Changes in Land Use, Design, Site Selection, and Building Standards: Investigate amendments to existing land use planning and zoning laws and regulations and building codes to account for expected climate change impacts when designing and constructing new infrastructure, repairing and upgrading existing infrastructure, and evaluating sites and areas suitable for infrastructure development. Bolster ongoing efforts by state agencies to factor climate change into future design, permitting, and building requirements. These land use, siting, design, and building standards should be reviewed on a routine basis to integrate new knowledge on predicted climate change impacts.
4. Enhance Natural Systems: Provide protection and resilience of infrastructure to climate change impacts by enhancing natural systems such as restoring wetlands, coastal features, and flood storage capacity. Restore the natural hydraulic features of watersheds to increase resiliency and capacity redundancy in wastewater systems, water supplies, and stormwater management resources.
5. Identify Lead Times for Adaptive Construction: Since different types of facilities have varying life spans, translate those timeframes into lead times for infrastructure replacement and rehabilitation. Energy infrastructure that has a lifespan of 30 years will have a different adaptation strategy than a power plant that may have a 50- to 60-year lifespan. The amount of time needed to permit, repair, improve, or build infrastructure will vary and should be identified.

The remainder of this chapter examines the vulnerability of various infrastructure sectors to climate change impacts and outlines no regret, short-term, and long-term strategies that will continue to be reviewed and considered for implementation regionally or statewide.

Energy

Without reliable energy services, the basic needs of residents, visitors, businesses, and governments cannot be met. Lost or damaged energy supplies would cause loss of power to homes, schools, government buildings, hospitals, industries, and businesses, as well as to various types of infrastructure, such as communications systems, which depend on energy to function.

Existing Resources

The electric power infrastructure is an interconnected system of power plants, substations, and hundreds of miles of high voltage transmission lines and local distribution wires. There are approximately 170 electric generating facilities throughout Massachusetts, ranging in size from less than one to hundreds of megawatts (MW). Several of the largest plants are located along the coast. The fuel used by generators to create electricity is diverse—natural gas, coal, oil, nuclear, and renewable sources such as solar, wind, hydro, and biomass. Massachusetts annually consumes about 56 million megawatt-hours (MWh) of electricity representing 46 percent of New England’s total consumption (U.S. Department of Energy, 2008). ISO New England reports that, in 2008, the Greater Boston area consumed about 40 percent of the state’s electricity. A large share of the electricity is generated in-state, but Massachusetts also relies on electricity from neighboring states.

Massachusetts is the largest consumer of natural gas in New England. The US Census Bureau reported that gas is the state’s largest energy source for home fuel (about 44 percent), and ISO New England notes that natural gas is also the leading energy source for electricity generation in New England as a whole (38 percent). Massachusetts receives its gas supplies via three interstate pipeline systems and via liquefied natural gas (LNG) tanker ships. Massachusetts has three liquefied natural gas import terminals. One is located on land in Boston Harbor and the other two are located 11 to 13 miles offshore. Ships connect to buoys at the offshore terminals, the LNG is gasified, and then it is transported via undersea pipelines. Gas is delivered to customers through 1,000 miles of underground transmission pipes and 21,000 miles of local distribution pipes.

Massachusetts is dependent on petroleum product imports from domestic and foreign sources. There are five major petroleum terminals along Boston

Harbor waterways and smaller terminals in other coastal communities. Almost 90 percent of the petroleum products are imported into the state by ship or barge. To reach inland regions such as western Massachusetts, petroleum is transported via trucks from in-state and out-of-state terminals. The oil terminals in Springfield receive petroleum via local underground pipelines fed from ships in New Haven, CT, and Providence, RI.

Impacts and Vulnerabilities

To assess climate-induced changes and impacts for this sector, assets were identified and organized into three broad subcategories: 1) facilities, including electric generation plants (nuclear, natural gas, oil, and coal), LNG terminals, propane plants, petroleum product terminals and storage facilities, and electric substations; 2) above-ground wires and pipes; and 3) below-ground wires and pipes.

The energy sector's three primary climate change concerns are flooding (due to increased precipitation and storm surge), extreme events (such as hurricanes and snow and ice storms), and increased temperature. These events can affect almost all infrastructure assets. In addition, climate change impacts that affect energy producing regions beyond Massachusetts' borders, such as the Gulf Coast, could cause greater frequency and severity of energy supply interruptions for Massachusetts.

The following are the predicted impacts on energy infrastructure:

- Extreme and more frequent weather events, including flooding, may damage energy production and delivery equipment such as generation plants (e.g. the Pilgrim nuclear power station), terminals, storage facilities and above- and below-ground wires and pipes. Damaged infrastructure will lead to interrupted service, degraded energy reliability, increased equipment maintenance or replacement costs, and adverse impacts to public safety.
- Sea level rise and storm-related flooding may require relocating coastal infrastructure, which would require new real estate acquisitions for replacement sites.
- Extreme temperature changes could result in an increased demand for cooling in summer and a decreased demand for heating in winter. One 2005 study of changes in Boston's heating and cooling demand indicates that, "depending on the climate scenario, household electricity consumption in peak summer months may be nearly three times that of the 1960-2000 average, with over 25 percent of the increase directly attributable to climate change" (Amato et al., 2005). Such changes also can shift energy production and use. For example, high temperatures reduce thermal efficiency of electric generation. This could challenge the ability of the electric system operators to meet peak electricity demands.
- There may be lengthened repair times and delays. Repair crews will find it more difficult to work in protective gear for extended periods in high temperatures, during prolonged rain or in extreme cold.

Potential Strategies

No Regrets Strategies

1. Encourage Energy Efficiency. Energy efficiency is both a mitigation and an adaptation strategy. Decreased energy demand defers the need for additional infrastructure and helps to avoid peak load outages.

Impacts of the Ice Storm of December 2008

From December 11 through December 18, 2008, central, western, and northern Massachusetts experienced a severe ice storm, which caused devastation over almost 7,000 square miles. The storm damage affected the energy and transportation infrastructure, homes and schools, and even the Appalachian Trail. Over one million customers were impacted by power outages with over 550,000 customers losing their electricity at the peak of the storm, and some for up to two weeks. This also caused additional damage, such as frozen water pipes in commercial and residential properties, as well as lost revenue. Countless trees were damaged, with downed trees and tree limbs blocking roads, damaging property and bringing down power lines.

The storm was very costly—the Federal Emergency Management Agency (FEMA) obligated over $32 million for reimbursement to seven Massachusetts counties for eligible costs; state costs exceeded $7 million and municipalities expended over $5 million. National Grid, one of the primary electrical suppliers in the area, claimed over $30 million in storm-related costs.

2. Educate Asset Owners and Regulators. Regulators, energy asset owners, and privately- and municipally-owned utilities should understand the future impacts of climate change on infrastructure and the benefits and costs associated with preparing for and responding to climate change.
3. Diversify Energy Supplies. To avoid reliance on supply from one geographical region that may be more vulnerable to climate change, utilities and other energy suppliers should continue to assess the diversification of their energy supply portfolios and factor in future climate change predictions.
4. Track Trends in Energy Demand, taking into account climate change forecasts. Regulators, energy asset owners, and privately- and municipally-owned utilities should carefully track changes in energy demand resulting from climate change and factor such changes into future planning and procurement strategies.
5. Plan for Changes in Consumers' Expectations Regarding Energy Types. Consumers have altered their perceptions about climate change. As a result, more consumers are requesting energy supplies from cleaner energy sources. Closely monitor consumer trends to anticipate the types of energy supplies that will be in demand, such as renewable energy and emerging biofuels, and the potential impacts that climate change will have on these new sources.

Short-Term Strategies

1. Utilize and Accelerate Deployment of New Energy Efficiency Technologies. Smart Grid technology may stabilize load requirements during high demand periods, thus ensuring supply and system integrity as well as in-creasing power reliability during storms, flooding, or high peak load.

A **Smart Grid** is a network for electricity transmission and distribution systems that uses two-way, state-of-the-art communications, advanced sensors and specialized computers to improve the efficiency, reliability, and safety of electricity delivery and use.

2. Encourage Research and Development of Renewable Energy Technologies. Renewable energy technologies such as solar, wind, tidal and wave power, and other emerging renewable applications are new and growing sources of electricity supply and jobs. They will diversify our electricity generation portfolio and reduce pollution.
   - Wind: Climate change (temperature, precipitation, humidity, solar) may lead to changing wind patterns. Design wind turbines to meet low-medium-high wind speeds. Monitor onshore, nearshore, and offshore wind patterns to determine optimal siting locations.
   - Solar: With enhanced monitoring and preparation, Massachusetts can rapidly protect its growing solar electric capacity from severe weather impacts, including panel degradation. Careful monitoring of the Massachusetts climate and better predictions will be necessary to determine the proper specifications of future photovoltaic investments.
3. Consider Undertaking a Regional Analysis of New England's Integrated Energy Infrastructure. Analyze climate change effects on interstate energy infrastructure. The New England states, along with the electric Independent System Operator of New England (ISO New England), and gas and oil industry representatives, should work together to develop a comprehensive regional analysis of climate change impacts on supply and demand as well as storm response.

Long-Term Strategies

1. Collaborate with other states and utilities to ensure the best-integrated strategies are deployed, particularly given the size of capital and operational investments in utilities infrastructure, and support facilities with long life-spans.
2. Utilities should work with land use planners at the state environmental and regulatory levels to secure necessary parcels to meet the need for energy infrastructure that is threatened by flooding, extreme storm events, and increased temperature.

Transportation

The Massachusetts transportation system is vitally important to the daily functioning and economic future of the state. The transportation sectors outlined in Table 5 and their respective infrastructure ensure economic vitality and quality of life by safely and efficiently moving people, goods, and services throughout the state.

Existing Resources

To appreciate the breadth and depth of our reliance on a diverse transportation network, Table 5 outlines the basic elements of the state's road and rail network and other transportation infrastructure.

Impacts and Vulnerabilities

The impact to the various forms of transportation, particularly along the coast, could dramatically affect the ability to sustain normal levels of commerce, public health, safety, welfare, and security, and to respond to natural or human-induced severe events. Coastal transportation infrastructure is most vulnerable to sea level rise and extreme weather events including high winds, waves, and storm surge. High temperatures and dense air conditions could increase runway length requirements to accommodate typically diminished aircraft performance in such weather situations.

Inland infrastructure also may be affected by changing precipitation patterns, extreme weather events, and increased temperatures. Massachusetts may not have sufficient alternative transportation modes and routes available in particularly sensitive locations to provide backup and continuity of service in responding to climate change effects.

Potential Strategies

No Regrets Strategies

1. Continue Maintenance of Existing Infrastructure. Maintain existing transportation infrastructure to minimize the chances of flooding or other damage that might occur before final or more permanent adaptation plans can be implemented.

TRANSPORTATION RESOURCE HIGHLIGHTS*	
ROADS	71,887 lane miles (60,970 local lane miles at 85 percent, 10,917 state lane miles at 15 percent) 5,116 inventoried bridges (3,550 state, 1,566 municipal) Vast majority of total freight in Massachusetts moves by truck ($307 billion commodity value, 196 million tons)
RAIL	438 million Massachusetts Bay Transportation Authority (MBTA) passengers per year, or 1.2 million passengers per day (5th highest transit ridership in U.S.) 175 cities and towns, with a total population of 4.7 million people, serviced by the MBTA 2,500 vehicles, 258 stations, 885 miles of track, 500 bridges, 20 miles of tunnels, 19 maintenance shops 2.65 million Amtrak riders per year (Boston's South Station is Amtrak's 6th busiest station in U.S.) Commercial rail traffic: 14 carriers carry about 500,000 rail carloads per year over 1,000 miles of track
AIR	The 39 public-use airports handled about 2.1 million operations (takeoffs & landings) and 26.0 million passengers in 2009. Of those totals, Logan Airport accommodated 345,300 operations and over 25.5 million passengers The other 38 public-use airports accounted for 1.75 million operations and 476,000 passengers Logan Airport managed 191.1 million pounds of cargo, 28.8 million pounds of mail, and 326.5 million pounds of express/small packages in 2009 198 private landing areas: 112 helipads, 47 landing strips/airfields, 38 seaplane bases, and one military landing strip
BUS	29 million passengers per year use 1,372 buses and vans provided by 15 Regional Transit Authorities MBTA operates 1,055 buses on 186 routes over 761 route-miles; THE RIDE, a paratransit service, operates 568 vehicles in 62 municipalities and averages over 1.58 million trips per year Boston's South Station provided about 190,000 bus trips for an estimated 5.7 million passengers in 2009; these figures do not include charter, tour, school, and non-South Station bus trips throughout the state
WATER-BORNE TRANSIT	2.7 million passengers and 590,000 vehicles per year on island ferries 1.22 million commuter ferry passengers per year 105 cruise ships from 15 cruise lines carry 300,000 passengers per year Port of Boston handles the majority of the state's bulk and containerized cargo; 11 ocean freight ports total
WALK/BIKE	12 percent Massachusetts residents and 24 percent Cambridge residents walk to work 48 percent of all downtown Boston trips are made by walking 13.3 percent walk and 1 percent bike to work in Boston (1st and 15th respectively of major US cities, and 1st in combined

Table 5: ***Massachusetts' Transportation Resources***

** References listed at the end of the chapter*

2. Expand the use of the statewide GIS-based system asset maps by combining them with updated floodplain mapping and revised peak flood flow calculations.
3. Formulate risk-based methods to evaluate service life of infrastructure assets against adverse climate change.
4. Update hydrologic and hydraulic analyses statewide, including engineering methods used in the calculation of peak flood flow rates, to reflect influence of climate change-induced events (e.g., the U.S. Geological Survey's Regionalized Peak Flow Equations for Massachusetts and the 50-year old National Weather Service's Precipitation Frequency Atlas, TP-40).
5. Research and Develop Engineering Solutions. The Massachusetts Department of Transportation and Massachusetts Port Authority should work with regional and municipal agencies to identify, develop and implement solutions—including reconstruction, removal, or relocation of vulnerable infrastructure—to protect existing assets from climate change impacts in the long- and short-term.
6. Protect Existing Infrastructure. Modifications include elevating, armoring, modifying, or relocating critical infrastructure. Airport, mass transit, port, and highway agencies should consider sizing stormwater management structures (e.g., pipes, culverts, outfalls) for future storm events and balancing upfront costs of incrementally larger structures today with the future costs of replacing an entire drainage system.

Short-Term Strategies

1. Public and private transportation entities should adjust standard maintenance and inspection procedures to take into account climate changes impacts, including increasing the frequency of routine inspections of coastal zone and inland bridges and drainage structures and initiating comprehensive regional asset damage inventories after major storm events.
2. Develop New Design Standards. Revise standards to be consistent with guidelines reflecting climate considerations issued by such entities as the American Association of State Highway and Transportation Officials, Federal Highway Administration, American Public Transit Association, Federal Transit Administration, U.S. Department of Transportation Maritime Administration, and the Federal Aviation Administration.

Long-Term Strategies

1. Encourage innovation across transportation sectors. Encourage use of new technologies at airports for navigation aids and airfield lighting systems that function better during storm events. New aircraft technologies could also improve landing and takeoff performance, potentially minimizing adverse impacts of more consistently high temperatures.
2. Enhance water-based transit options in affected coastal and riverine areas as a long-range transport alternative and as an interim back-up to damaged infrastructure.
3. Develop financing mechanisms. Evaluate and implement as necessary new ways to fund the anticipated expenses, including construction and long-term maintenance and operation costs, to address climate change impacts at the state and local levels.

Water Resources

Water-related infrastructure includes multi-component systems involved in procuring, treating, and distributing drinking water; collecting, treating, and discharging wastewater; managing stormwater; and using dams, levees, seawalls, and other structures to control surface hydrology. Most of the facilities that support these infrastructure resources are publicly owned by municipalities.

Existing Resources

Maintaining infrastructure associated with potable water is critical to the public health and safety of Massachusetts residents. Approximately 95 percent of the 6.5 million residents living in Massachusetts obtain their drinking water from one of the state's 531 community public water supply systems. The remaining 5 percent of Massachusetts residents obtain water from one of the estimated 550,000 private wells. Raw water from approximately 82 percent of the water sources is treated prior to being distributed for public consumption.

Approximately 79 percent of Massachusetts' 6.5 million residents discharge 785 million gallons of treated sewage into the state's waters each day through over 20,000 miles of pipe and 126 treatment facilities. According to the Massachusetts Water Resources Authority (MWRA), the Deer Island Sewage Treatment Plant alone treats an average of 350 million gallons of sewage per day from about 2.1 million people in 43 metro Boston communities (MWRA, 2010). Another 21 percent of the homes, municipal buildings, and businesses (Massachusetts Infrastructure Investment Coalition, 2007) are not connected to a sanitary sewer system and discharge sewage to an on-site subsurface sewage disposal or to an approved treatment facility with a state groundwater discharge permit. There are 280 municipal and private facilities that discharge wastewater to groundwater (Felix, 2009).

Stormwater infrastructure is comprised of municipal separate storm sewer systems and combined wastewater and stormwater systems. Historically, stormwater management systems consisted of pipes, culverts, dams, detention basins, and storage reservoirs and were designed to convey stormwater, control peak flows, and prevent flooding. More recently, stormwater control measures have been designed to treat and infiltrate stormwater.

There are hundreds of dams and levees controlling water flow in rivers and streams throughout the state. Many of these are large structures that hold back significant volumes of water. Seawalls, groins, and other coastal flood control structures are common along the 1,500 miles of Massachusetts coastline.

Impacts and Vulnerabilities

Sea level rise could potentially inundate numerous municipal collection systems and some wastewater treatment plants along the Massachusetts coast and inland to a point where it could make economical sense to abandon them after their current useful lives. At other locations, it may make sense to use larger regional facilities (or expand existing upland facilities) for the treatment of wastewater and then use decentralized systems to discharge the treated water back in its original watershed. In general, to preserve water management operations (such as wastewater treatment, stormwater systems), it is important to take measures to reduce stress on river and coastal infrastructure such as dams, levees, and seawalls.

Another challenge is that existing Massachusetts Stormwater Management Standards apply only to sites undergoing development or redevelopment which are subject to review under the Wetlands Protection Act, Rivers Protection Act, or the Water Quality Certification Program, and do not apply to other upland areas that generate stormwater.

Potential Strategies

No Regrets Strategies

1. Continue to Facilitate Enhancement of Natural Systems. Redirect inflow from traditional stormwater collection systems into systems using low-impact design technology and restored natural hydrology to keep stormwater on site and increase available capacity and groundwater recharge. Increased use of groundwater recharge would also assist in reducing polluted runoff to surface waters, decrease flooding, and enable existing dams, levees, and other flood control structures to operate during more extreme storm events.
2. Continue to Promote and Expand Conservation and Reuse Efforts. Enhance ongoing efforts to conserve potable drinking water, reduce wastewater discharge, and decrease stormwater runoff. Implement the Massachusetts Water Conservation Standards and advance the use of treated wastewater, especially in commercial and industrial settings.
3. Coordinate Information Gathering. Coordinate efforts of land use planners, facility designers, and regulators in the collection and analysis of basic geographical, geologic, and engineering information needed to characterize vulnerabilities of water-related infrastructure systems.

Short-Term Strategies

1. Offset Impacts to Water Supplies. Consider revising the Massachusetts State Plumbing Code

Mother's Day Storm—Infrastructure Overwhelmed!

The 2006 Mother's Day storm began Friday, May 12 and, for the next 100 hours, dumped up to 15 inches of rain on many North Shore communities in Massachusetts. A U. S. Geological Survey flood gauge at Lowell showed that the flood level in the Merrimack River reached 59 feet, making it a 40-year occurrence event. On May 13, two days before flood levels in the Merrimack River peaked, a force main to the Haverhill Wastewater Treatment Plant gave way, spilling 35 million gallons per day of untreated sewage into the Merrimack River. The break occurred when the rapidly moving river in a tributary washed out a culvert that ran beneath a section of a power easement roadway and the force main. As the storm continued, waters flowed over bridges and into the streets and basements throughout the region. It took almost a week to repair the break.

The Department of Environmental Protection estimates that, had the water level in the Merrimack risen another two to three feet, wastewater treatment plants in the Greater Lawrence Sewer District would have lost their pumping stations and power to their treatment plants, resulting in major additional discharge of untreated sewage to the Merrimack River. It is also likely the drinking water treatment facilities in Tewksbury, Lowell, and Lawrence would have also become incapacitated.

to encourage and (in some cases) require water conservation. Assess the potential to increase water supplies through the reuse of non-potable water and use of greywater technologies.

2. Make Near-Term Changes to Publicly Owned Treatment Works. Evaluate flood-proofing vulnerable drinking water and wastewater facilities by raising the elevation of structures above predicted flood stages, installing watertight doors and windows, replacing wet/dry well pumps with submersible pumps, increasing emergency back-up provisions to keep all key equipment operational, and relocating vulnerable equipment. Ensure emergency and contingency plans include the use of backups, such as emergency generators for power generation.
3. Address Stormwater Flows
    a. For new development and redevelopment projects in upland areas, DEP should investigate developing requirements similar to those currently contained in DEP's Wetlands/ Water Quality Certification Regulations, which promote stormwater infiltration into the ground (i.e., at its site of origin where feasible), rather than direct run-off toward central stormwater drainage systems that discharge to surface waters. This will help decrease flooding, improve aquatic baseflow, recharge aquifers, and improve the quality of surface waters;
    b. Expand implementation of low-impact development as a stormwater mitigation mechanism;
    c. Periodically evaluate the long-term control plans for Combined Sewer Overflows (CSO) developed by the 24 Massachusetts CSO communities to determine if additional efforts are needed to protect the environment and public health from more frequent CSO activations. Free-up wastewater treatment and conveyance capacity by continuing to identify and remove infiltration and inflow from wastewater collection systems; and
    d. Expand public outreach and education efforts concerning the negative impacts of stormwater on flooding, the quality of rivers and streams, and the quantity of water in aquifers.
4. Enhance the SRF Program. Review and potentially modify the State Revolving Fund (SRF) Program —which provides $100 million of low-interest loans for water and wastewater projects—to encourage communities to address climate change impacts and avoid investments in highly vulnerable areas.

Early Experiences in Climate Change Adaptation at MWRA

During the 1980's and 1990's, the Massachusetts Water Resources Authority (MWRA) designed and constructed the massive Deer Island Wastewater Treatment Plant to meet federal regulations and provide environmentally sound treatment of wastewater from two million people in the metropolitan Boston area. A key component of the facility was construction of a 9.5 mile long, 24-foot diameter outfall tunnel into Massachusetts Bay, bored in solid rock 100 feet under the bay. Anticipating that the outfall would be in service for 50 to 100 years, MWRA engineers accommodated for changes in sea level in its design. As the sea level rises, water leaving the tunnel will push against a higher head, reducing the capacity of the tunnel and the treatment plant. In 1989, the designers reviewed the most current projections in climate modeling and decided to raise the entire plant about 1.9 feet higher to accommodate potential sea level change for at least the first 50 or 60 years of the facility's service.

5. Compile critical information on water and wastewater treatment facilities, including elevation data, location of pump stations and other affiliated structures; identify the location and capacity of stormwater conveyance waterways and structures.
6. Analyze how current flooding conditions and U.S. Federal Emergency Management Agency (FEMA) flood maps will change under certain climate change scenarios.
7. If appropriate, revise the Wetlands Protection Act Regulations and other regulatory tools that cite FEMA maps (which are required to reflect current and not future conditions) to reflect forecasted flood boundary alterations that may be linked to climate change.
8. Implement a program to educate water resource utility owners and operators on the vulnerabilities of their assets to climate change impacts.

Long-Term Strategy

Use Adaptive Management Techniques to Develop Long-term Infrastructure Sustainability Plans. Develop long-term sustainable solutions that include a mix of both decentralized resources and regional approaches. Some solutions may involve centralized or decentralized physical assets.

Dam Safety and Flood Control

As the major flood control structures used in Massachusetts, dams have been constructed for agricultural, industrial, and energy generation purposes. Many hydropower dams were constructed in the 17th century. The Department of Conservation and Recreation (DCR) Office of Dam Safety is responsible for the oversight of dam safety. Under current laws, responsibility for periodic inspections, inspection report preparation, and mandated preparation of emergency action plans for "high hazard potential" structures falls to the dam's owner.

Among the predicted climate changes for the Northeast U.S., extreme storm events, sea level rise, and increased intensity of precipitation pose the greatest threats to flood control structures (for more on flood control structures along the coast, such as sea walls, see section on 'Coastal Engineering for Shoreline Stabilization and Flood Protection' in Chapter 8) in Massachusetts, which, for the most part, were originally designed to control floodwater volumes and velocities based on historic weather patterns.

Existing Resources

There are more than 2,800 known dams in the state, most privately owned and operated. Of the known dams, at least 1,349 are not subject to the state dam safety regulations, due to their size, design, and ownership status. Of those subject to regulation (1545 dams):

- 304 are classified by the DCR as having a "high hazard" potential (dams located where failure will likely cause loss of life and serious damage to key infrastructure and the built environment);
- 727 are classified as having a "significant hazard" potential (dams located where failure may cause loss of life and may damage key infrastructure and built environment or cause temporary loss of use of services and key facilities); and
- 514 are classified as having a "low hazard" potential (dams located where failure may cause minimal property damage, and no loss of life is expected).

Unlike the case in many western and mid-western states, dikes and levees are not common in Massachusetts and other eastern states. A few highly specialized flood control structures are located in the state, including a hurricane storm surge barrier in New Bedford, flood diversion canals in North Adams, and levees located along the Connecticut River in Springfield, Holyoke, and Chicopee.

Many dams no longer serve the original purpose of their designs. Additionally, many contribute to major water quality problems—they can create a reservoir of contaminated sediments and severely limit the ability of waterways to use natural systems to help maintain clean water.

Potential Strategies

No Regret Strategies

1. Update modeling protocols and precipitation data. Use the Northeast Regional Climate Center data from 1993 (or most recent) in future safety analyses and design work until more up-to-date climate change data becomes available.
2. Prepare or revisit emergency action plans. Use approaches and assumptions in the preparation of emergency action plans that consider the most updated estimates of likely levels of precipitation, flooding, and extreme storm events, particularly when preparing or revising emergency actions that address "high hazard" dams.
3. Encourage cooperative efforts with federal and regional agencies to improve dam safety. Cooperate closely with federal agencies, the Association of State Dam Safety Officials, and various state agencies as new analytical data are developed and made available to the planning, engineering, and regulatory communities, including DCR data on dam locations and risk status for the entire state.

Short-Term Strategies

1. Develop Dam Planning within State Agencies. State agencies, with the Massachusetts Emergency Management Agency (MEMA) taking a lead role, should coordinate risk assessment planning for high hazard potential dams, using the worst-case assumptions of climate change impacts.
2. Mandated Insurance Program. Evaluate the value of establishing insurance requirements for dam owners and insurance companies to acknowledge and financially cover liabilities, anticipate future threats, address potential vulnerabilities, and reduce the state's expense in emergency response and cleanup.

Long-Term Strategies

1. Continue support for the Division of Ecological Restoration's river restoration program. The program helps facilitate dam removal with the

goals of preserving river continuity, maintaining the natural cleansing capability of waterways, and preventing water quality degradation associated with contaminated sediments build-up behind a dam.

2. Creative financing via federal and state opportunities. Explore various state and federal funding opportunities and evaluate expanding their eligibility criteria to provide low-interest loans for beneficial dam removal projects.
3. Continue to encourage the establishment of public, non-profit, and private partnerships to enhance efforts to target the removal of dams that either are deemed high hazard under DCR's rankings or which cause water quality or habitat impairments.
4. Seek to remove potential institutional barriers and evaluate the benefits of a streamlined dam maintenance and removal review and approval processes.

Solid and Hazardous Waste

Solid and hazardous waste infrastructure comprise solid waste landfills, combustion facilities, transfer stations, and hazardous waste treatment, storage, and disposal facilities. Other entities that have the potential to generate hazardous waste in the event of a natural disaster include waste generators such as retailers with hazardous materials (e.g., pharmacies and chain retail stores), certain chemical handling businesses, fuel tank farms, waste transporters, and residences equipped with heating oil tanks and containing hazardous household products.

Existing Resources

Massachusetts hosts 25 active solid waste landfills, seven solid waste combustion facilities, 230 active handling facilities (e.g., transfer stations), several large recycling facilities (e.g., the Springfield Materials Recycling Facility), and over 700 inactive landfills, many of which are located near environmentally sensitive wetland areas.

Most of the 12 hazardous waste treatment, storage, and disposal facilities (TSDFs) are not located in floodplains or coastal areas. One exception is Clean Harbors Braintree, New England's largest hazardous waste TSDF, which is located on the Fore River in Weymouth. Most facilities store their hazardous waste in containers that can be moved easily. Tank areas are above-ground and are diked to protect them from heavy stormwater run-off. In an emergency, hazardous waste in drums and tanks can be removed and shipped to a less vulnerable facility quickly, provided that roadways are passable.

Industries with hazardous waste and hazardous materials, however, are concentrated in coastal cities. There are approximately 680 large quantity hazardous waste generators and several thousand very small quantity generators in Massachusetts. Smaller generators may lack resources for emergency planning, which may increase the risk of abandoned hazardous materials during a flooding or storm event.

Impacts and Vulnerabilities

Climate change impacts could cause flooding of low-lying solid waste landfills, generation of large volumes of solid waste following a major storm event, and release of large amounts of fuel and hazardous materials (such as paints, solvents, and pesticides) from flooding of private homes and businesses.

More rainstorms and associated runoff could cause structural damage, increased release of leachate, or even exposure of waste at landfills located in historic wetlands and other sensitive locations. Erosion could increase because culverts and detention basins associated with solid waste facilities may not be able to handle increased runoff. More leachate could lead to a need for larger storage tanks or could cause increased discharge of leachate into the sewer system. If flooding conditions persist, contaminants from within the landfill could be carried away by floodwaters. Waste management services could be disrupted if facilities are closed due to damage or if capacity is exceeded due to an unexpected surge in solid waste production.

Potential Strategies

No Regrets Strategies

1. Enhance Geographic Information Systems (GIS) data for solid and hazardous waste management facilities.
2. Ensure that contingency plans for hazardous waste treatment, storage, and disposal facilities and large quantity generators include a description of procedures, structures, or equipment used at the facilities to prevent flooding and run-off from hazardous waste handling areas.

Short-Term Strategies

1. Develop better mapping data to identify solid and hazardous waste facilities that would be vulnerable to rising sea level and new, more frequent, or more severe flooding.
2. Consider requiring all solid and hazardous waste facilities operating in areas prone to coastal or inland flooding to prepare adaptation plans. This could be addressed through the permit renewal process.

3. Encourage local government agencies that oversee the operation or building of industrial facilities with hazardous waste and hazardous materials in areas prone to flooding to develop outreach materials on flood adaptation measures.
4. New retail gasoline fueling stations should be sited and designed using most recently available FEMA flood study and map information, incorporate additional provisions to address sea level rise over design life when located in a coastal flood zone, and contain appropriate containment systems, while older and abandoned gas stations should be identified and evaluated for their vulnerability under various climate change scenarios.
5. Enhance state and local efforts to regularly collect household hazardous waste.
6. Solid and hazardous waste infrastructure and emergency planning efforts should contemplate the need for possible temporary, large-scale storage of hazardous waste and materials generated from flooded properties.
7. Implement the Massachusetts Disaster Debris Management Plan as approved by the Federal Emergency Management Agency (FEMA). Implementing the recommendations of this plan will significantly enhance the abilities of local and state governments to respond to the challenges of managing disaster debris.

Long-Term Strategies

1. Develop a regional contingency plan for household hazardous waste collection during flood events.
2. Develop a detailed inventory of existing and potential hazardous waste generators and calculate the total hazardous waste facility storage capacity for Massachusetts.
3. Evaluate modification of the siting and design requirements for new and expanded waste management facilities to account for predicted site-specific climate change impacts that could be expected during the life of the facility.

Built Infrastructure and Buildings

Existing Resources

The built infrastructure and buildings sector encompasses the design, building, and operation of publicly- and privately-owned buildings. Many of them are situated in areas along the coast or major waterways and floodplains that may be particularly vulnerable to climate change impacts like storms and flooding.

Impacts and Vulnerabilities

Building design standards are based on historic climatic patterns. As climate patterns are likely to be very different in the future, the existing built infrastructure in the state could be adversely affected. Thermal stresses on building materials will be greater, cooling demands will be higher, existing flood-proofing may be inadequate, floodplains may extend to areas with unprotected structures, heat island effects may increase, corrosion of building materials may accelerate due to salt water intrusion, and building-related illnesses, primarily caused by mold build-up, may increase.

Potential Strategies

Strategies designed to protect existing and future buildings from predicted climate change impacts should consider the location of the existing/proposed building, the timing of when a projected climate change impact is expected to occur, the life-span of the structure, historical significance of the existing structure, and the cost and engineering involved with moving, demolishing-recycling, or protecting the structure.

The Spaulding Rehabilitation Hospital and Projected Sea Level Rise

Emergency facilities must do more than respond to natural disasters, they must also be planned and developed with these potential threats in mind. When planning its new eight story, 132-bed facility in the Charlestown Navy Yard, the Spaulding Rehabilitation Network considered both the current FEMA floodplain maps and sea level rise projections of between 0.27 m & 1.4 m (0.9 & 4.6 ft) over the next 75 to 100 years.

Designers concluded that a rise in sea level of two feet over 75 years was a reasonable projection, resulting in a shifting of the 100-year floodline. Taking into account height restrictions and the relationship of the building to the surrounding topography, the finished floor of the building has been established at 0.41 m (1.35 ft) higher than the new 100-year flood elevation and 0.11 m (0.35 ft) higher than the new 500-year flood elevation (as projected for 2085). Additional precautions include mechanical and electrical installations located on the roof, no patient facilities located on the ground floor or below, patient rooms having key-operable windows for emergency ventilation, and basement parking protected by establishing the top of ramp elevations set at the same level as the ground floor.

No Regrets Strategies

1. Require analysis of new construction and major renovation projects to include provisions to address predicted climate change impacts.
2. Use permitting and environmental review processes to recommend that new construction and renovation projects consider the use and protection of basement and first-floor levels, the installation of enclosures for roof-top equipment to protect them from more severe weather exposure, use of green roofs to absorb additional precipitation and decrease cooling needs, enhancement of site work to include bio-swales, the use of permeable pavement, construction of wetlands to handle surface water run-off, and raising the height of damp-proofing of foundations to accommodate increased flooding.
3. Consider climate change impacts in developing universal (accessible) design guidelines for all future projects.

Short-Term Strategies

1. Consider allocation of additional space in new building design and existing building retrofits to house the necessary mechanical equipment to handle increased heating, ventilation, air conditioning, pumping, or generator capacity.
2. Consider purchasing appropriately-sized generators and pumps to handle increased flooding and properly-sizing building structural components to carry additional precipitation and wind loads, and improve drainage around buildings.
3. Assess when and where to fortify existing buildings and when to move, demolish-recycle, or abandon vulnerable structures.
4. Plant shade trees to decrease solar/thermal load on buildings.

Long-Term Strategies

1. Evaluate modification of review and approval processes and building codes to require consideration of climate change impacts and life-cycle costs in public and private developments and construction activities.
2. Take steps to ensure that the life span of a building is in line with anticipated climate changes (i.e., a 50-year building will not be located in an area where flooding is projected in 30 years' time).

Information and Communications Technology

Information and communication technology stability and security in the face of climate change should be considered a high priority because of the pervasive influence of and reliance on this sector in daily life.

Existing Resources

Telecommunication networks are classified as either fixed (e.g., telephone and cable services using copper wire, coaxial cable, or fiber optics) or mobile (e.g., cellular and satellite connections). Information and communication technology services can be broken down into telecommunication services (broadband, mobile voice and data, and fixed voice) and broadcast services (television and radio). In Massachusetts, there is one primary local exchange carrier (Verizon). There are ten cable TV providers serving over two million subscribers in 308 of the state's 351 cities and towns (MassDTC, 2009). Massachusetts also benefits from 35 licensed full- and low-power TV stations (FCC, 2011a), 120 community TV stations (MassHome, 2010); 272 Federal Communications Commission-licensed radio stations (FCC, 2011b), and 745 licensed telecommunications operators (Mass DTC, 2011).

Impacts and Vulnerabilities

Information and communications infrastructure that could be affected by climate change effects include mobile and fixed radio, TV and cellular towers, satellite dishes, central office facilities, switching and base stations and foundations, manholes, underground pits, and thousands of miles of surface and subsurface wires, cables, and conduits.

The primary climate change impacts on this infrastructure would be extreme weather events, including flooding, erosion, heavy rainfall, coastal storm surges, and hurricanes. Additionally, high wind, lightning, and ice storm events could damage or destroy utility lines, poles, and towers. Increased temperatures and solar radiation could lead to a greater demand on certain equipment for cooling capacity and more rapid deterioration of aerial transmission cables. Salt spray from coastal storms and saltwater intrusion may increase corrosion of telecommunication towers and other equipment in coastal areas. While New England is forecasted to have an overall increase in annual precipitation, the region also may experience more seasonal drought periods, which could lead to forest fires and resulting infrastructure damage.

These varied events could adversely affect public safety, emergency, and transportation-related communications, as well as personal and business activities. The implications of these effects include increased capital and operating expenditures to repair, replace, redesign, or relocate telecommunications infrastructure at a faster rate. Other implica-

tions include a need to increase customer rates to cover infrastructure damage or replacement costs, to offset decreased productivity and maintain overall economic activity when systems are disrupted, and to re-establish compromised public health, safety, and security operations.

Some elements of the information and communication technology infrastructure have relatively long life spans and long lead times for design, approvals, and construction. They also may require high capital costs to implement.

Early in 2009, Governor Deval Patrick initiated an IT Collaborative to "organize the voice of the Information Technology industry through the creation of a sustainable, cross-cluster dialogue of stakeholders in business, government, and academia". This approach should include an emphasis on adapting the industry quickly to predicted climate change effects, such as increasing use of wireless technologies, achieving higher resilience standards (e.g., in mobile and fixed communication towers and transmission equipment), and reducing vulnerability and remediation costs.

The trend toward more wireless technology and the continued rapid evolution of information and communication technology should help the industry, as well as other impacted sectors dependent on this technology to adapt more successfully to extreme weather events and other predicted climate changes.

Potential Strategies

No Regrets Strategies

1. Inventory facilities, including transmission lines, towers, and satellite dishes; underground and underwater structures; computer terminals and peripheral equipment; broadcasting stations; and emergency communication systems for vulnerability to coastal and inland elements of climate change.
2. Support rapid updating of topographic and floodplain mapping.
3. Continue regular maintenance of existing infrastructure. Undertake a regional and national analysis of information and communication technology adaptation in the face of climate change, taking into account the lifecycle costs of these systems.

Short-Term Strategies

1. Identify lead times for climate change impacts and for redesigning, revamping, repairing, replacing, or relocating infrastructure elements. Adaptive planning should help accelerate the overall planning process, realizing that the technology itself is undergoing rapid change.
2. Incorporate climate change concerns into design standards and site selection while accelerating new sustainable technologies.

Long-Term Strategy

Assess the vulnerabilities of competing technologies to climate change risks, and ensure decision-makers involved in network upgrades or realignments are properly informed by this information. (Maunsell, 2008)

Commonalities Among Sectors and Strategies

Although the chapters in this report are organized into specific sectors, there are several interconnections among and within them. This section attempts to address those overlaps and interconnections between the Key Infrastructure sectors and the other chapters, and between the state's climate change mitigation efforts.

Key Infrastructure Interconnections

1. Energy and Transportation Sectors: Impacts to the energy and transportation sectors will influence the state's ability to adapt to climate change impacts affecting other forms of infrastructure, as well as in other sectors such as public health and economy, and will influence the state's ability to mitigate climate change. Losses of energy production and distribution and access to modes of transportation are identified as major climate change vulnerabilities in all sections of this report. Without a resilient and reliable source of energy and effective means of transporting people, goods, and services, it will be difficult for Massachusetts to adapt to climate change, prepare for or recover from emergency situations, and maintain state and national security objectives. As such, those strategies identified in the energy and transportation sectors should be considered not only as ways of protecting those individual sectors, but also as ways of protecting the other sectors throughout the state and region from the effects of climate change.
2. Water Resource Sectors: Many adaptation strategies identified to address potential climate change impacts are very similar among the three major water-based infrastructure resources: water supply, wastewater, and stormwater management. Examples from two broad categories, "design and operational features" and

"enhanced natural hydrology," demonstrate the interconnectivity of some key strategies among the water-based infrastructure sub-sectors.

a. Design and operational features: Strategies involving water conservation measures are common to both water supply and wastewater management. Reduced demand for water through measures such as water conservation, grey water reuse, and reduction in unaccounted-for water losses (e.g., leaking pipes), not only reduce the demand on public water supplies, but also reduce the amount of wastewater that needs to be managed. Reduced water use can protect against concerns about insufficient water supplies, especially during predicted periods of extended summer drought. Wastewater should be considered a commodity having considerable value in reuse, rather than just a waste flow that has no value. Additionally, less stress on these infrastructure systems generally results in greater resiliency to handle emergencies that may be caused and/or aggravated by climate change impacts. This will also result in reduced operational, management, and replacement costs. Low-impact design strategies also provide synergy of benefits to multiple water resource sectors.

b. Enhanced natural hydrology: Nature is effective in providing clean drinking water and managing wastewater and stormwater. Water resource managers are more often adopting watershed-based strategies that take a holistic view of water resource issues in a manner that considers the natural hydrology of a geographic area. Future decisions on water supply, wastewater, and stormwater management that mimic and reinforce the natural hydrology of a geographic area (e.g., a watershed) will enable natural systems to help manage future climate change impacts.

Lessons from the Dutch—Use of Natural Systems

The Dutch are well-known for their prowess in engineering structures designed to keep floodwaters out. In a country where about half the population lives below sea level, over 10,000 miles of flood defense contributes to the $2.5 trillion worth of existing infrastructure upon which the Dutch are highly dependent. In recent years, the Dutch have increasingly supported the use of natural barriers, such as sand dunes and marshes, to ease the force of storms and retain floodwaters and now ban drainage of existing marshes in further support of natural ecosystems over artificial systems.

Furthermore, the Dutch are adopting approaches aimed at carefully accommodating, rather than resisting, flood waters where possible. The essence of this principle (of integrated coastal policy) is: flexible integration of land in sea and of water in land, making use of materials and forces present in nature. The Dutch plan to return 222,000 acres of land to floodplain buffers for use as marshland or natural forest land. They have placed a moratorium on new flood-prevention infrastructure in some towns and are lowering, repositioning, or removing some dikes. This marks a significant change in the way they think of water by embracing land uses or construction types that tolerate soggy conditions.

Natural hydrologic systems have evolved to be flexible and adaptable to the extremes of weather phenomena, so strategies that reinforce and use natural systems can be very successful and cost-effective. These watershed-based approaches could be integrated more fully in the development of MassDEP's Comprehensive Water Resources Management Plans, which are required for certain water resources permitting and considered in funding assistance decisions.

3. Increased Conservation Measures and "Green" Designs

The State's vulnerabilities to climate change may be reduced if it decreases its reliance on and use of certain services. Additionally, natural ecosystems provide a number of services which support built infrastructure resources. By diminishing or eliminating non-climate stressors to infrastructure, that infrastructure may have more capacity to be resilient to climate changes. Here are a few examples to help illustrate this benefit:

a. Energy—Energy efficiency improvements and lowered demand will reduce loads on stressed electrical infrastructure while mitigating climate change through a reduction in greenhouse gas emissions.
b. Transportation—Reducing vehicle miles traveled reduces physical and capacity stresses on roads, bridges, and tunnels, increasing their resiliency to climate and weather-related impacts. When the population diversifies its travel patterns, individuals have greater flexibility in their transportation options. Reducing vehicle miles travelled also has implications for lower greenhouse gas emissions, providing climate change mitigation and reducing the need for adaptation.
c. Urban forests—Urban forests can perform a variety of vital infrastructure services. Trees are very effective in filtering pollutants from the air, as well as reducing volumes and pollutant loads from stormwater runoff. Increased urban vegetation and tree canopy, as well as innovative strategies such as green roofs, are also very effective in reducing the heat island effect in urban areas, which can reduce the demand and stress on energy infrastructure.

Charles River Natural Valley Storage Project

In 1910, the Charles River was dammed, creating the "Charles River Basin." In subsequent years, however, residents feared that the dam would significantly increase flooding during major storms. Brought in to study the precipitation data, the US Army Corps of Engineers noted a surprising lack of flooding in the towns north of Newton. It attributed this to a series of isolated wetlands that naturally store and gradually release water to the Charles River, buffering the effects of particularly rainy seasons on the river's water levels. In light of this information, Congress authorized the purchase of 17 wetlands (8103 acres) for $8.3 million, creating the "Charles River Natural Valley Storage Area." At the time, the Army Corps of Engineers was also considering a $100 million dam construction project to serve the same purpose, but decided in favor of the wetland solution.

Since 1974, when the purchase was authorized, the decision is believed to have created benefits of over $7.5 million to the local economy and has prevented flood damage estimated at $3.2 million. Additionally, property values bordering these wetlands sell at a 1.5 percent premium. Use of this natural solution over a significantly more expensive engineered solution has already paid for itself in a way the second dam never could. The Charles River Natural Storage Area is a living example of an economical, environmentally conscious solution.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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