# Climate
# Change
# Adaptation
# Act

The Climate Change Adaptation Act:

The Science Behind S. 2355

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# Executive Summary

Senator Maria Cantwell (D-WA) introduced the Climate Change Adaptation Act on November 14, 2007. If it is passed, the bill will direct the federal and state governments to prepare the nation to adapt to the challenges of climate change. In this report, we have examined the challenges posed by climate change, potential solutions to those problems, and the current readiness of the government to respond to those challenges. First, we examine the legislation to discover the plan, who will implement it, its source of funding and its ultimate goal. Key points include integrating the plan into current federal agency policy, addressing identified climate vulnerabilities, working with non-governmental and non-federal organizations to exchange information and to coordinate planning and implementation, and improving existing capabilities for dealing with climate change.

Climate change is a multifaceted environmental problem, with foundations in natural sciences and engineering. For purposes of this analysis we assume that Congress has determined that public security, health, and welfare are the top priorities for adaptation, as indicated in the proposed legislation. Technical solutions are not presented within the bill: it is left up to the states to devise regionally appropriate solutions. So we analyzed climate change solutions that would likely be pursued by states, including their advantages and pitfalls, based on an evaluation of the challenges identified within the bill. Coastal erosion, natural hazards and infrastructure were chosen as because they are the most crucial for coastal states, they are the most likely to impact the United States according to the Intergovernmental Panel on Climate Change (IPCC), and the United states is already being impacted by these three effects of climate change. Technological solutions to these problems such as monitoring and early warning systems are considered in this report, as are the benefits of ecosystem restoration. Finally, natural systems are compared to technology with respect to cost and benefit.

It is clear that government action is needed, but the bill contains contradictions that raise questions. While the bill addresses the dangers to coastal states from sea level rise, it fails to address the fact that central states are at greater risk of drought due to climate variability. Seawalls are excellent barriers to coastal erosion, but they can harm the natural ecosystems associated with the same areas; the bill does not help to determine whether seawalls or coastal wetlands and mangroves should be the primary solution for coastal erosion. Flood prevention technology for large cities is an obvious solution to sea level rise, but the bill fails to consider the impact of the energy consumed and carbon dioxide expended by running the pumps. Adaptation to climate change will take place within the context of significant uncertainty, thus measuring the success of this bill will depend in large part on identifying quantifiable parameters acceptable to the nation, in the face of some unknowns as to the true extent of the risks.

# Introduction

## What Legislation are we Examining?

On November 17, 2007, in the first session of the 110th Congress, Senator Maria Cantwell (D-WA) introduced S. 2355, the Climate Change Adaptation Act. This coincided with the release of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report's Summary for Policymakers, which the bill cites as justification for action. In its report, the IPCC states unequivocally that climate change is occurring, and we will experience its effects soon than we think. Unfortunately, the National Academy of Sciences has reported that the United States (US) is not prepared for the impacts of climate change, because information is not being disseminated to the appropriate decision-makers, or fully utilized when it is made available.

The Climate Change Adaptation Act addresses climate change as an established fact and includes a comprehensive list of its expected environmental impacts. These include impacts to environmental services, human health, agriculture, energy uses, water resources, wildlife and other natural resources, and infrastructure. The bill posits that this constitutes a direct and pressing threat to national security and overall human welfare. It then offers adaptation as a solution, sidestepping the debate over whether mitigation efforts can avert these impacts. The bill states that in order to create a feasible adaptation plan, structured planning and funding are a necessity, as is improved research on climate change and communication between agencies. It does not propose specific solutions to the many problems it enumerates, but our research led us to pinpoint natural hazards, coastal erosion and infrastructure as the primary areas that will be impacted by climate change. In this report we identify solutions to these specific challenges.

## Why is Focusing on the Science Important?

There are technological, financial, social and cultural obstacles to the bill's success, but a solid scientific foundation will be the most critical component for any adaptation solutions. Scientific indicators must provide the basis for allocating resources under this legislation and will be crucial in measuring whether desired outcomes are achieved. Therefore, during this semester we are approaching climate change adaptation as an environmental rather than administrative problem and evaluating the feasibility of solutions from a primarily scientific perspective. Next semester we will focus on policy and administrative issues.

# What is the Environmental Problem?

The Climate Change Adaptation Act addresses climate change's projected impacts on the coastal United States. The Act does not consider climate change mitigation, nor does it judge whether climate change is of natural or anthropogenic causes. Instead, the bill aims to prepare the US for climate change's likely impacts, by increasing the resilience of coastal regions.  While there is not a complete consensus about the causes of climate change, a consensus is developing and there is a clear observed trend of increasing temperatures over the last century (Figure 1).

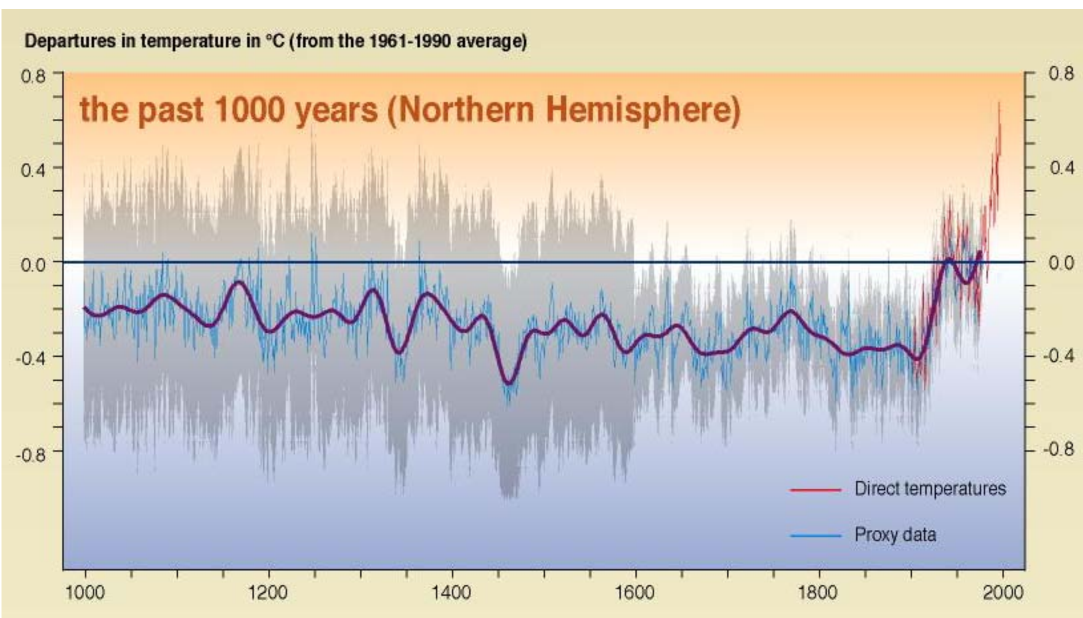


Figure 1: Departures in temperature from 1961-1990 average: 1000 AD to 2000 AD (IPCC, 2001)

Although the bill describes widespread climate impacts in its policy discussion, its prescriptions focus on coastal regions, particularly a few key areas likely to be significantly impacted by climate change: public health and welfare, infrastructure, and coastal ecosystem services. The bill targets these areas for adaptation efforts.

The potential societal impacts associated with coastal climate changes are broad. Increases in extreme weather events, in combination with sea level rise, may lead to increased storm surge, coastal erosion and flooding. These changes will likely impact transportation and infrastructure. Overflows from sewage treatments plants due to increased precipitation will impact water supplies and public health. Water-borne diseases and resulting human losses could become more prevalent (WHO, 2008). In addition, some proposed and potential adaptation policies, for example desalinization plants, are energy-intensive, and would further exacerbate an already strained US energy system (EPA, 2007a).

Increases in global mean temperatures due to climate change are also expected to stress ecosystems services such as water filtration and biomass production (e.g. wood, soil, food sources), which will lead to economic losses. An increase in severe weather events will also lead to increased forest fires and flooding. A temperature increase of 1.5 – 2.5°C, in the moderate range for climate projections, is predicted to increase extinction risk for 20 – 30% of currently assessed plant and animal species (IPCC, 2007). These ranges are uncertain projections; impacts could be larger or smaller, just as climactic warming could be more or less severe.

## Coastal Erosion

As of 2008, more than half of the United State population lives within 50 miles of a coast, which constitutes only 11% of total United States land area. One way in which anthropogenic coastal erosion impacts ecosystems is through salt-water intrusion, which occurs when freshwater is contaminated by saltwater. This renders the freshwater non-potable and also interrupts the normal functions of coastal ecosystems. These ecosystems, including wetlands, estuaries and bays (bayous), are among the most productive natural systems in the world. They are critical to sustaining aquatic and terrestrial food webs, and in maintaining balances for marine fish, shellfish, and wildlife (Gagnon-Lebrun & Agrawala, 2008). The primary conduits of saltwater intrusion are dredging canals, used for oil and gas wells; these structures severely alter ecological wetland communities (FEMA, 2006).

Natural coastal erosion occurs when seawater collides with coasts, resulting in rock weathering. Erosion impacts the coast and coastal habitats including bays, estuaries and shallow waters. Coastal erosion is caused by sea-level rise, wave action and currents, and sediment deficiencies. The construction of dams, levees, seawalls, canals, and groins, have complex effects on erosion. In some circumstances, infrastructure may exacerbate coastal erosion by limiting sediment and sand dispersal, inhibiting their replenishment on beaches and in wetlands, but these barriers also reduce erosion by blocking wave action.

Inland states also suffer the impacts of coastal erosion when rivers, especially large rivers like the Mississippi, experience changes in flow and pathways. Unlike the rivers themselves, development along them is static and cannot easily react to these natural fluctuations. When these rivers change direction structures built along their coasts may be severely damaged (FEMA, 2006).

## Natural Hazards

Natural hazards, including storm surge, heavy precipitation, flooding, inundation, drought, and fires, can cause damage to coastal communities as well as the natural environment. Of these, storm surge and flooding are of particular concern to coastal states, as the terrain of coastal states tends to be at a lower elevation and more proximate to the sea, or in the case of inland coastal states, large lakes and rivers. Storm surge occurs when ocean, lake or river water is forced towards the shore by the strength of a storm; typically, storm surges involve large wind and wave action. Waves can erode beaches and coastal highways and damage building foundations and other structures such as barriers, floodgates and canals.

75% of the US population lives less than 10 meters (m) above mean sea level, putting a large proportion of the total population at risk of the negative impacts of flooding with projected sea level rise. When water surplus is not drained, either naturally or through existing infrastructure, it accumulates, moving towards the equilibrium at the lowest topographical point. Because water is rather dense, it can move extremely quickly and with great force towards its equilibrium state. Decreased surface absorptive capacity, particularly in urban areas due to conversion of vegetative cover to paved surfaces, can magnify flooding extent. Absorptive capacity is also lost when wetlands are converted for farmland or urban development. Vegetative cover absorbs excess water and with its loss, the likelihood of flooding increases (Huston, 2008).

## Infrastructure

Climate change will likely increase the rate of infrastructure degradation and failure as a result of the increased frequency of extreme weather events and other long-term impacts, such as salt-water exposure. Roads abutting coastlines are particularly vulnerable to the impacts of salt-water or salinity exposure, because continuous contact with salt-water can cause infrastructure failure. As moisture evaporates over time, the dissolved salt takes its crystalline, solid form, and it expands, causing stress failures in pavement. The average lifespan of roads is 20 – 40 years, but salinity damage as a result of flooding, storm surge, and saltwater intrusion can severely decrease their serviceable lifespan (O'Flaherty, 2003).

A study of over 500 bridge failures in the US between 1989 and 2000 found that 53% of these failures were caused by floods and scour (Kumalasari & Hadipriono, 2003). Scour, which can be naturally occurring, is the process by which sediment is removed from the channel of a river during floods. It contributes to the erosion of infrastructure like bridges and is increasingly likely under climate change (Warren, 2007).

Urban infrastructure will also likely be impacted by climate change. One of the major causes of subway service disruption and safety hazards is flooding (Sander, 2007); between 1999 and 2007, the entire New York City subway system was temporarily shut down on three separate occasions due to flooding from unexpected heavy rains (Chan, 2008). The causes of flooding in the New York City subway system are complex. For example, on August 8, 2007, flooding of the system occurred due to heavy rainfall that was not adequately predicted by the weather service, which also happened to occur during high tide, thus increasing the pressure on the drainage system. In addition, the pumps that normally drain the water were not prepared to handle flooding of this magnitude and neither was the sewer system to which the floodwater was pumped (Figure 2). This lead to the flooding of subway tunnels requiring the New York City Transit Authority to suspend subway service, which made it virtually impossible to get around in New York, a city which is highly dependent on public transportation. The increased occurrence of this type of flooding event may lead to more permanent damage. Climate change models predict that sea level rise will lead to increased flooding in the New York area with storm surge likely to occur in New York City. Thus, the flooding of the New York City subway will become a more common occurrence requiring an adaptation strategy.

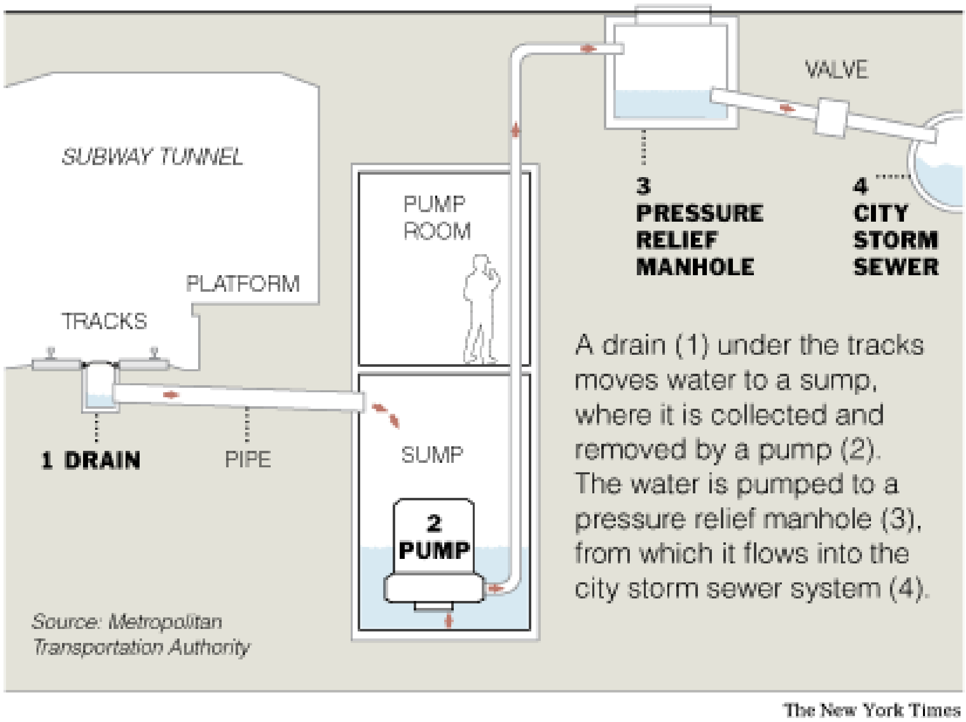


Figure 2: The pumping system meant to handle flooding in the New York City subway system Source: http://www.nytimes.com/2007/08/08/nyregion/08cnd-weather.html?hp

Identifying the nature and science of environmental problems enables the focused development of appropriate policy and scientific solutions to the problems. Within the context of our analysis of the Climate Change Adaptation Act, this review of coastal erosion and natural hazards, with their combined effects on infrastructure, lays the groundwork for this report to address the proposed solutions.

# What are the Proposed Solutions?

The environmental problems associated with climate change impacts can be addressed by policy and management solutions as well as science and technological solutions. The Act establishes a policy framework for identifying management, science, and technological solutions.

The Climate Change Adaptation Act specifies several steps that the US needs to take to prepare for the anticipated impacts of climate change. First, it amends the National Climate Service Act (NCSA) by shifting the focus of the National Climate Program from research to adaptation. Specifically, it provides for the development of a National Strategic Plan for Climate Change Adaptation and for the completion of regional assessments of coastal and ocean vulnerability. These assessments will lead to the development of a national coastal and ocean adaptation plan, which will pave the way for state and local governments to develop their own adaptation plans. Additionally, the Act amends the Coastal Zone Management Act of 1972 (CZMA) by providing for the distribution of grants to states whose adaptation plans are consistent with the national plan.

## Policy and Management Solutions

The solutions proposed by the bill are largely organizational and administrative, involving multiple levels of government as well as non-governmental entities. Most broadly, the National Strategic Plan for Climate Change Adaptation will coordinate all climate change research and planning activities in the US and ensure that adaptation planning is incorporated into all federal agencies' policies when appropriate. At a regional level, the vulnerability assessments, to be conducted by NOAA's newly established National Climate Service, will establish priority targets for adaptation funding and lead to the development of general adaptation strategies appropriate to each region. Finally, the adaptation grants awarded to coastal state governments will promote the implementation of these strategies at the local level; local governments have the best knowledge of which projects will most effectively meet their climate change adaptation needs.

Other policy and management solutions are described below.

### *Insurance*

One issue the legislation directly addresses is insurance; the bill explicitly requires reform of the National Flood Insurance Program (NFIP). However, insurance executives view climate change as the biggest threat to their industry (Fialka, 2008), and many insurers are abandoning US markets because of climate change vulnerability and unpreparedness (PlaNYC, 2008). Other legislation currently before Congress could expand the National Flood Insurance Program to relieve homeowners and private insurers in a broader range of emergency situations. However, these changes would do nothing to slow the growth of population along coastlines, which has been doubling every 10 to 15 years (Fialka, 2008). Therefore, NOAA will have to develop a plan that allows Americans continued access to insurance markets without encouraging excessive risk-taking. Currently, the NFIP does not use climate change predictions to determine eligibility (Dickey, 2008). One solution might be to use NOAA's vulnerability assessments to develop risk-based premiums for a national insurer of last resort that would cater to all Americans in case of natural disasters (Cohen, 2008). Premiums could be reduced in areas where local governments have implemented adaptation strategies recommended by the federal government.

### *Early Warning Systems*

Though it is not specifically detailed in the bill, according to the IPCC, an effective early warning communication and response system is crucial to preventing loss of life and reducing economic impacts from natural hazards. The Third International Conference on Early Warning (EWC III, 2008) concluded that the main elements of a successful system were knowledge of risks, technical monitoring, a warning service, communication and dissemination of warnings, and community response capability. Making certain the messages are easily understood and include advice on how to react in the event of the emergency is crucial (EWC III, 2008). Several means of communication must be used including public meetings, press releases and web pages. The IPCC report explains that many factors reduce the ability or willingness of people to flee an imminent disaster, including the notice period, access to evacuation routes, perception of need to protect property and possessions, and concern for pets (IPCC, 2007). Additionally, it is suggested that early warning systems should occur for all sorts of extreme weather related events, not just hurricanes. For example, the city of Toronto has set up a system to alert public health officials 60 hours before the start of heat waves

(Daley, 2007). If an early warning communication and response system is employed and used more frequently, the public will become more accustomed to the occurrence of irregular weather events and they will respond to them more efficiently and in ways more likely to protect them from harm.

## Science and Technology Solutions

Addressing climate change impacts and planning for adequate adaptation requires scientific and technological solutions alongside the policy options described in the previous section. Since the bill does not specify particular science and technology options for adaptation, this report focuses on likely solutions, gleaned from scientific, governmental, and intergovernmental bodies. The aim of these proposed solutions is to reduce loss of human life and to reduce direct infrastructure damage and non-market damage in the most cost-effective manner. Here we focus on scientific and technological solutions to adaptation along the US coast in three broad categories:

- Modeling and monitoring tools;
- Infrastructure design, including water and transportation infrastructure; and
- Coastal protection, contrasting ecological services with built approaches.

### *Modeling and Monitoring*

Modeling and monitoring tools are useful decision-making and planning instruments that will aid in implementation of adaptation strategies along the US coast. Climate and hurricane models can provide state and regional adaptation plans with information on likely impacts and time horizons for those impacts. Monitoring tools will enable the identification of vulnerable infrastructure prior to its complete failure, thus lessening adaptation and infrastructure upgrade costs.

*Climate Modeling*

The quality and capability of climate models has improved dramatically in the past decade. Atmosphere-Ocean General Circulation Models (AOGCMs) use a three-dimensional pixel grid to represent the earth's system. Values for temperature, humidity, wind-speed and other parameters are entered for each point enabling future climate prediction and reproduction of past events (Houghton, 1997). States can now use high-resolution model projections to develop better-informed adaptation strategies. For example, in 2002, the New York City Department of Environmental Protection (DEP) utilized a coupled hydrodynamic and atmospheric climate model to recreate the effects of past hurricanes. This process enabled effective planning for the placing of storm surge barriers within the harbor and the Hudson River.

*Hurricane Modeling*

Presently, NOAA uses hurricane models routinely to predict hurricane formation, strength, and direction before storms make landfall. As there are a wide number of models with different strengths and weaknesses, NOAA uses over a dozen discrete models divided into two broad prediction classes: tracts and intensity. Tract models predict the likely course the hurricane will follow, while intensity models predict whether hurricanes are likely to strengthen or weaken over a given period. In addition, coupled models can predict an increase or decrease in storm intensity alongside changes in typical inland storm paths (Kennedy et al., 2002). Planners can use this information to predict future hurricane paths inland and plan accordingly.

*Infrastructure Monitoring Technologies*

In order to detect infrastructure damage, an array of tools is necessary to improve monitoring capabilities and decision-making processes. Bridges are a critical type of infrastructure and they are particularly sensitive to collapse. Networks of sonar sensors can be used to monitor scour-critical bridges in vulnerable areas (e.g., Alaska). Sensing, nanotechnologies, and "smart" technologies are available to monitor a wide range of threshold sensitive infrastructure including buildings, bridges, bridge decks, and pavement (TRB, 2008; Klein et al., 1999). Finally, x-ray machines can identify hidden cracks in girders and computerized sensors can track changes in stresses on steel beams; both are essential to bridge structural integrity (TRB, 2008).

### *Infrastructure Solutions*

Since infrastructure is in place for long periods, it is particularly susceptible to long-term climatic changes. Investment of adaptation funding in infrastructure such as transportation, and water and sewage systems will therefore achieve especially high yields.

There are two options for infrastructure upgrades in the face of climate change: strengthening infrastructure to withstand climate change impacts or developing new infrastructure with higher adaptive capacity. Strengthening would include increasing water pumping capacity in subways, raising highways and railroads by re-ballasting or adding pavement, and retrofitting bridge footings with ripraps to protect them from scour (EPA, 2007b, NYC DEP, 2008). New infrastructure should not be built alongside flood plains, because new construction tends to be particularly vulnerable in these areas. Adaptation options for infrastructure will need to focus on engineering and design standards that take into account future climate conditions, particularly for water systems and transportation infrastructure.

*Transportation*

When industry standard design life values were established for transportation infrastructure, climate change and its associated increase in extreme weather events were not considered (Klein et al., 1999). On average, pavement lasts 10-20 years, rail track less than 50 years, and bridges and tunnels 50-100 years. As a result of higher levels of precipitation , elevation of streets, bridges and rail lines, more robust drainage canals near coastal roads and additional pumping capacity, especially for tunnels and subway systems, will be needed along with more robust, water-resistant insulation of energy infrastructure and electrical wiring systems (especially for subways and monitoring sensors).

*Water and Sewage*

The increase in severe precipitation events will also necessitate adaptation solutions to our water supply system. The principal component of both water and drinking water systems is piping. Of the existing pipes in the US, metallic pipes installed in the past 20 – 40 years are the ones experiencing the most frequent failures due to corrosion and environmental stresses (Rahman, 2007). In response, new materials such as glass-reinforced plastic, Polyvinyl Chloride (PVC), and polyethylene of raised temperature resistance (PE-RT), are being used to replace pipes made from concrete, clay or ductile iron (EPA, 2007c). Plastic compounds have a high resistance to water and chemical corrosion; however, their health impacts and lifecycle costs are presently unknown.

Nitrogen control and phosphorous removal technology will be important for water treatment plants to ensure water is treated sufficiently during extreme precipitation events before being released into water bodies. Energy-efficient wastewater treatment technologies will become the norm rather than an upgrade. Larger-diameter and steep sewers with incorporated sediment traps will also be necessary.

### *Coastal Protection*

Coastal protection can be achieved through engineering or through the use of existing ecosystems.

*Seawalls*

Seawalls are engineered to impede inshore water flow resulting from sea level rise. Similar to levees, they must be built continually for long stretches to ensure gaps do not allow flooding inland (Mendelsohn, 2000). In addition, rising sea levels and increased wave action intensity may force large amounts of water over seawalls; this problem, termed 'over-topping' must be managed if seawalls are employed as an adaptation strategy.

There are other drawbacks to the use of seawalls. When seawalls are constructed, they can impede barrier islands' movement towards the shore. As sea levels rise, the marsh cannot move inwards, and is lost to the encroaching sea, reducing the natural ability of the coast to act as a buffer against extreme weather events (Bouma, Schram, & Verbeke, 2008). Once these natural barriers are lost, seawalls may need additional strengthening to buffer against the resulting increase in wave action (Kennedy et al., 2002).

*Ecosystem Services*

Natural land loss causes a variety of impacts, including changes in the local hydrology, changes to the ecosystem's filtration and waste buffering capacity, as well as changes to natural storm buffering functions (Chopra et al., 2005). Coastal wetlands, such as salt marshes or mangrove swamps, are well known storm buffers. Plants, including trees, root mats, and grasses, trap water through their complex vegetative structure, slowly releasing it back into the surrounding environment, thus reducing the risk of flooding (EPA, 1995). Since many coastal wetlands have been replaced by development, restoration is required in many regions. Therefore, the most effective plan would conserve the existing ecosystem by limiting the potential sources of degradation, recover a partially degraded ecosystem by reducing vegetation stresses and enabling sediment buildup to allow vegetation to reestablish, and completely rebuild the ecosystem by creating new wetlands.

Using wetlands to buffer flooding impacts is considered more effective and economically viable than artificial technological solutions (Barbier, 2007; Hansen, Biringer & Hoffman, 2003). For example, the many expensive engineering projects in the Mississippi River basin implemented in the past 150 years to control floods and improve river navigation resulted in the loss of 6.9 million hectares of natural wetlands and an increase the region's vulnerability to flooding (Chopra et al., 2005). Salt marshes in Louisiana are critical storm buffers that reduce the energy of wave action and absorb excess water. In turn, this reduces the likelihood of flooding and infrastructure damage under hurricane conditions (Penland & Sutter, 1988). Climate change is likely to reduce the resilience of our coastal ecosystems making ecosystem restoration, monitoring, and protection of critical importance.

Barrier beaches and islands also serve as effective storm barriers; like wetlands and other ecosystems, they reduce wave and wind action and intensity, dampening the effect of the storm inland and providing an essential habitat to coastal flora and fauna. Through the protection they provide, barrier beaches also enable the formation of salt marshes (Figure 3). Through the dynamic interaction of these two ecosystems, barrier beaches and salt marshes provide strong buffering capacities for natural hazards and coastal erosion. Restoring barrier islands may be an effective adaptation solution to protect coasts in some regions.

Figure 3. Barrier Islands providing natural protection to coastal areas.

*Coastal Ownership*

According to the Arctic Climate Impact Assessment, a 50-cm rise in sea level will likely cause coasts to retreat by 50 m where land is relatively flat (Berner et al., 2004). Typically, states' immediate coastal boundaries are held as "public trust tidelands" (Titus, 1998); however, with projected sea level rise, coasts will move significantly inwards. Coastal development can exacerbate problems raised by climate change; as sea levels rise, natural storm buffers including wetlands may be lost to the encroaching sea. Despite the challenges in large-scale resettlement programs, some states have been successful in these efforts. New Jersey began the Coastal Blue Acres land acquisition program in 1995, targeting land in storm prone areas (Easterling, Hurd, & Smith (2004). Land was also acquired to act as buffer strips, protecting regions further inland and decreasing wetland losses. Policy tools, which may aid coastal ownership restructuring, include setback lines and rolling easements.

*Setback Lines*

Setback lines are development boundaries based on the distance from the coast and vulnerability of the land. This policy tool can prevent development in areas prone to erosion and storms (Titus, 1998). However, setback lines can be challenging to draw, since projected sea level rise is relatively uncertain. In addition, while they may prove effective immediately, their usefulness is questionable once advancing coastlines reach beyond their boundary, a likely scenario for many jurisdictions in the 21st century. This can create a problematic situation where states may be required to purchase land in the future or force people from their land (Titus, 1998).

*Rolling Easements*

Rolling easements are particularly useful given that small increases in sea level can lead to coastal retreat inland, and projected sea level rise is still relatively uncertain. Rolling easements do not limit shoreline development as heavily as setback lines; rather, they require owners and developers to recognize state ownership within a certain distance from the shore, and eventually cede their ownership rights over time. Rolling easements also prevent problems of seawall development infringing on wetland preservation, thereby ensuring natural buffers move inland with the coast. Texas is one state currently employing this planning model.

# Measuring the Success of the Solutions

The Climate Change Adaptation Act calls for a multi-year process to ensure that coastal States and vulnerable areas of the US are prepared for the expected impacts of climate change. Therefore, the ultimate success of the proposed Act will be determined by the effectiveness of the adaptation solutions designed and implemented as a result of the Act. As such, a monitoring and evaluation strategy will be needed and will need to provide answers to the following key questions:

- Are people in coastal regions safer?
- Are contingency plans in place for emergency responses?

- Have monitoring systems been developed and implemented?
- Have the impacts of climate change been consistent with expectations and models?
- Has funding been well spent?
- Is infrastructure able to withstand extreme weather events?
- Is the health of US coastal ecosystems being maintained?

## Defining Success

The Act sets forth three key phases of implementation: (a) Policy Framework, (b) Institutional Compliance, and (c) Risk Reduction. A comprehensive monitoring and evaluation strategy will need to focus on assessing the success of the Act at each stage of its implementation. Although all three phases are important, ultimately, the long-term significance of the Act will depend on how successful it is in terms of reducing risks to people, property and ecosystems. Figure 4 presents a schematic representation of the three phases of the Act that will be monitored and evaluated, with an emphasis on risk reduction.

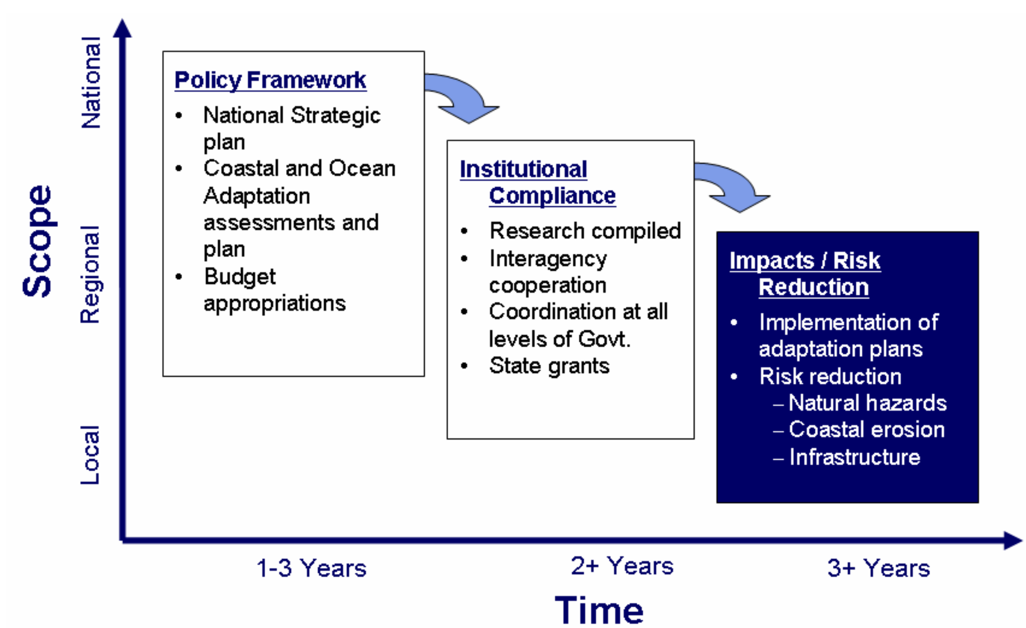


Figure 4. Schematic representation of the three areas of the Act that will be monitored and evaluated, from national to regional to local levels, as a function of time.

### *Adaptation Solutions*

Successful long-term implementation of the Act will ensure that coastal states and vulnerable communities are provided with sufficient information, tools, technical assistance, plans and funding to adapt to the expected impacts of climate change. As discussed earlier, adaptation solutions can be broadly organized into two types: Policy & Management Solutions, and Science & Technology Solutions. Given the nature of the key environmental problems outlined earlier in the report, however, the monitoring and evaluation strategy presented here will focus on the Science & Technology Solutions, specifically focusing on three components: (1) Infrastructure, including water and transportation systems, (2) Populations, including people and personal property, and (3) Ecosystems, including salt marshes and mangroves. Table 1 presents the expected outcomes for each of these components, as well as the key indicators of success and the corresponding monitoring strategies.

| Impacts and Risk Reduction | Outcomes | Key Indicators of Success | Monitoring Strategies |
|---|---|---|---|
| **Infrastructure** | - Aging infrastructure retrofitted, rehabilitated or replaced | - Regulatory requirements for public infrastructure<br>- Revised optimal design lifetimes | - Ongoing inventory of vulnerable infrastructure<br>- Establishment of procedures for infrastructure management |
| | - Infrastructure failures avoided | - Real-time monitoring and threshold profiles<br>- Improved ability to withstand weather impacts | - Technologies for monitoring and evaluation of key infrastructure (e.g. pipes and bridges) |
| | - Relocation of vital infrastructure and strategic assets from vulnerable areas | - Reduced outages, downtime and economic loss due to coastal flooding and storms | - Updated inventory of vital assets located within vulnerable and high risk areas |
| **Populations** | - Lowered risk of human losses | - Fewer people living in vulnerable coastal areas | - Inventory of vulnerable areas; census data |
| | - Enhanced ability to predict storm intensity and path | - Early warning systems, emergency preparedness and response systems, evacuation programs | - Evaluation of predictive models compared to actual events |
| | - Programs to rebuild or relocate damaged property | - Restructuring of NFIP and coastal Insurance program/premium structures | - Comparative analysis of insurance coverage and damage claims |
| **Ecosystems** | - Development restricted in coastal zones and erosion countermeasures implemented | - Reduction in rate of coastal development in high risk areas<br>- Coverage of coastal acquisition and easement programs | - Inventory and assessments of coastal areas |
| | - Wetlands and ecosystems restored and protected | - Ecosystem integrity and land area maintained or increased | - Assessments of land area and ecosystem health; effectiveness of restoration strategies |
| | - Fewer flooding events and shorter duration of impacts from coastal flooding and storm surge | - Reduction in frequency and intensity of flooding events along coastal regions | - Standardized methods for measuring storm surge and flooding events |

Table 1. Outcomes, Indicators and Monitoring Strategies for the Impacts/Risk Reduction Phase of the Act.

### *Challenges of Monitoring and Evaluation*

Given the national scope of the Act and the complexities inherent in coordination and information sharing between federal, state and local agencies, monitoring and evaluation will face challenges that will need to be resolved by NOAA and participating agencies. Foreseeable challenges include:

- **Oversight**: what agency will be responsible for oversight of the national adaptation program and who will be responsible for implementation of the program at each level of government and local area?
- **Enforcement**: what are the enforcement steps, and what agency is responsible for enforcement and assessment of penalties for non-compliance?
- **Information sharing**: the effective collection of data for each indicator will require extensive networks of information to be updated and monitored for compliance. How will this information be managed and what agency will be responsible for ensuring timely reporting of data?
- **Feedback loops**: how will periodic monitoring and evaluation results get incorporated into the process to ensure institutional learning in order to reach the expected results?
- **Time**: how will the plans measure long-lived infrastructure assets that are designed to last centuries?

# Controversial Aspects of the Solutions

Globally and nationally, climate change is a controversial issue. Not surprisingly, given the current public debate in the US over climate change and its policy implications, there are several key controversies surrounding the science of adaptation policy as presented in the Act. The following are the three most salient controversies that will need to be addressed.

## Scientific Uncertainties

The Act accepts climate change as a fact; however, there is controversy over uncertainties regarding the specific, regional and local impacts of climate change and adaptation options (IPCC, 2007). This uncertainty has important implications for adaptation policy, management, and implementation. The result is controversy surrounding the uncertainties over the specifics of climate change impacts (i.e., *which* impacts will be significant for a particular region or city), the time frame of the impacts (*when* will they occur), which adaptations options are best (*what* and *how*), and how much these options will cost (EPA, 2004).

These uncertainties have led to a controversy between those that think immediate adaptation actions are necessary (e.g., proponents of the Act), and those that think that more certainty and scientific knowledge are needed before adaptation actions are developed and implemented (some opponents of the Act). The Act addresses this controversy by calling for a multi-step process that involves assessments, research and coordinated implementation by federal and state agencies. If the Act is adopted into law, the controversy over the need for adaptation actions in the face of many and varied uncertainties will be replaced by increased consensus over the need for both further research and immediate action.

***Controversies over Ecosystem Services***

Coastal wetlands, specifically salt marshes and mangrove swamps, provide effective water storage capacity during flooding, protection from coastal erosion, and are more cost-effective in providing these services than man-made structures or engineered adaptation solutions. The scientific controversy regarding environmental services involves research and management models relating to ecosystems as either (a) providers of key environmental (and adaptation) services, or (b) as having intrinsic and extrinsic non-use values (McFadden, 2008). This controversy over *why* ecosystems are important could be replaced with a consensus that they *are* important, with coordinated and focused research on: (i) how to better protect ecosystems by maintaining their integrity (IPCC, 2007); (ii) how to better monitor ecosystem health, integrity and stresses, and (iii) how to conduct more effective restoration of ecosystems. As New York City has shown with its innovative watershed-approach to securing its freshwater supply, primarily from the Catskill/Delaware area (NYC DEP, 2006), environmental services and ecosystem integrity can be directly related (Malcolm, et al., 2000).

***Adaptation vs. Mitigation***

There is a controversy regarding the science and engineering aspects of adaptation as addressed by the Act stemming from an imbalance in the amount and depth of research that is currently being conducted regarding adaptation and mitigation (Hulme, et al., 2007). In short, we know much more about the scientific and engineering aspects of mitigation than we do about adaptation. Paradoxically, however, while the Act establishes parameters for adaptation research in the US, there is, as yet, no federally mandated research initiative on mitigation. There will need to be more coordinated research efforts that relate our current level of understanding with regards to mitigation to a comparable level of understanding with regards to adaptation. Without a balanced scientific understanding of both mitigation and adaptation options, climate change will make adaptation more expensive, more complicated, and less efficient (Pew Center on Global Climate Change, 2008).

A further controversy is related to the nature and focus of adaptation and mitigation. With scientific, technological and engineering advancements, adaptation options will likely be increasingly effective at reducing risks resulting from climate change impacts. Our increasing, yet relative, success at adaptation may paradoxically reduce the incentives to mitigate the causes of climate change in the minds of the general public and policy makers. In this scenario, effective adaptation could create a negative feedback loop for mitigation policy and implementation, and perhaps curbing carbon emissions and sustainable development policies will be seen as less imperative. Given the recent track record of the US with regards to international mitigation initiatives, this controversy is of particular importance.

# Conclusion

### Does the Act Successfully Address the Science?

The Climate Change Adaptation Act is an important and far-reaching policy in that it clearly establishes the need to consider climate change adaptation as a national priority. With a strong emphasis on research, information sharing and coordination, the legislation calls on policy makers to think, plan and prepare for climate change. However, the strengths of the Act as a policy tool do not fully compensate for its shortcomings in its scope and in its failure to address key issues.

A key strength of the Act is the importance it places on research regarding climate change and adaptation. In addition to expanding federally mandated research on climate change, it provides a coordination structure for information sharing and interagency cooperation between NOAA and the ongoing Global Change Research Program. The Act also seeks to provide coastal states and vulnerable regions sufficient funding to properly plan and implement local adaptation options.

Another key strength of the Act is its multi-year strategy in establishing expected outcomes and milestones, at the national, regional and state levels. The Act establishes clearly defined outcomes at different levels and phases of implementation: (a) Policy Framework, (b) Institutional Compliance, and (c) Risk Reduction. This differentiated and multi-step approach establishes a national policy process through which future research and implementation can be adjusted according to the lessons learned in the initial phases of research and implementation.

The Act, however, also has key shortcomings. The Act does not address some of the major controversies involved with climate change adaptation science and policy. Specifically, and in light of the current emphasis on the environment as a national priority, it does not set forth a position regarding the importance of protecting and restoring coastal ecosystems as part of the adaptation plan. Further, the potential conflict and contradiction between adaptation strategies and mitigation strategies are not addressed by any of the provisions of the Act. Given the complementary and inter-related nature of climate change adaptation and mitigation, the focus exclusively on adaptation may lead to a situation where effective adaptation supersedes and eliminates the view that there is a need for mitigation policy in the US.

In this context, the importance of the Act cannot be overstated. Passage of the Act would not only establish a far-reaching policy precedent regarding climate change adaptation in the US, but it would also lay the foundations for future international leadership regarding adaptation research, science and technology. The US, for example, would be better prepared to provide technology-transfer services to developing countries that may not have the resources (human, material or financial), to conduct the necessary research. With an effective adaptation policy, other policies addressing climate change, such as mitigation policies, could potentially follow. In light of the upcoming presidential and congressional elections in the US, and the expected changes with regards to climate change policy, the Act represents a step, albeit an imperfect one, in the right direction.

# References

Barbier, E.B. (2007) "Do Mangroves Reduce Expected Storm Damages? Valuing the Storm Protection Service of Coastal Wetlands." 15th Annual Conference of the EAERE. Thessaloniki, Greece.

Berner et al. (2004). Arctic Climate Impact Assessment: Impacts of a warming arctic. Cambridge University Press.

Bouma, J. J., François, D., Schram, A. & Verbeke, T. (2008). Assessing socio-economic impacts of wave overtopping: An institutional perspective. Coastal Engineering, in press, 1-7.

Chan, S. (2008). Why the Subways Flood. The New York Times, June 25, 2008. Retrieved June 24, 2008 from http://cityroom.blogs.nytimes.com/2007/08/08/why-do-the-subways-flood/.

Chopra K., Leemans, R., Kumar, P. & Simons, H., (eds). (2005) Ecosystems and Human Well-Being : Policy Responses (Vol. 3): A Report of the Millennium Ecosystem Assessment. Washington D.C.: Island Press

Cohen, S. (2008). We Need a Real National Rainy Day Fund. The New York Observer. Retrieved July 10, 2008 from http://www.observer.com/2008/we-need-real-national-rainy-day-fund.

Daley, B. (2007). US lags on plans for climate change. The Boston Globe. Retrieved August 11, 2008, from http://www.boston.com/news/nation/articles/2007/04/05/us_lags_on_plans_for_climate_change/.

Dickey, G. (2008). The Potential Impacts of Climate Change on U.S. Transportation. The National Academies. Web Page. Retrieved July 13, 2008 from http://www7.nationalacademies.org/ocga/testimony/Climate_Change_Impacts_on_US_Transportation.asp.

Easterling, W., Hurd, B., & Smith, J. (2004). Coping with Climate Change: The Role of Adaptation in the United States. Pew Center on Global Climate Change.

Federal Emergency Management Agency (FEMA). (2006). Hurricane Hazards: Storm Surge. Retrieved June 17, 2008, from http://www.fema.gov/hazard/hurricane/hu_surge.shtm.

FEMA. (2006). Guidelines and Specifications for Flood Hazard Mapping Partners. Retrieved June 17, 2008, from http://www.fema.gov/plan/prevent/fhm/gs_main.shtm.

Fialka, J. (2008). Will Climate Change Shrink the Insurance Industry? Earth News. Retrieved July 13, 2008 from http://www.earthportal.org/news/?p=992.

Gagnon-Lebrun, F. & Agrawala, S.(2006), Progress on Adaptation to Climate Change in Developed Countries: An Analysis of Broad Trends, ENV/EPOC/GSP(2006)1/FINAL, OECD, Paris.

Hansen, L. J., Biringer, J. L. & Hoffman, J.R. (eds). (2003). Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. World Wildlife Fund. Retrieved July 21, 2008 at http://assets.panda.org/downloads/buyingtime_unfe.pdf

Houghton, J. T., Filbo, G. M., Griggs, D. J., & Maskell, K. (1997). IPCC technical paper II: An introduction to simple climate models used in the IPCC second assessment report. Cambridge University Press, UK.

Hulme, M. et al. (2007). Limits and barriers to adaptation: four propositions. Tyndall Briefing Note No. 20. July 2007. Retrieved July 22, 2008 from http://www.tyndall.ac.uk/publications/briefing_notes/bn20.pdf

Huston, M. (2008). The Need for Science and Technology in Land Management. The International Development Research Centre. Retrieved June 18, 2008 from http://www.idrc.ca/en/ev-29587-201-1-DO_TOPIC.html.

Intergovernmental Panel on Climate Change (IPCC). (2001). Climate Change 2001: Synthesis Report. Retrieved June 18, 2008 from http://www.ipcc.ch/graphics/graphics/2001syr/large/05.16.jpg.

IPCC. (2007). Working Group II Report "Impacts, Adaptation and Vulnerability". IPCC Fourth Assessment Report. Retrieved June 18, 2008 from http://www.ipcc.ch/ipccreports/ar4-wg2.htm

Kennedy, V. S., Twilley, R. R., Kleypas, J. A., Cowan, J. H. Jr. & Hare, S.R. (2002). Coastal and Marine Ecosystems & global climate change: Potential Effects on US Resources. Pew Center on Global Climate Change, pp 1-64.

Klein, R.J.T., Nicholls, R.J. & Mimura, N. (1999). Coastal Adaptation to Climate Change: Can the IPCC Technical Guidelines be Applied? Netherlands:Kluwer Academic Publishers.

Kumalasari, W. & Hadipriono, F.C. (2003). Analysis of Recent Bridge Failures in the United States. *Journal of Performance of Constructed Facilities* 17(3) 144-150

Malcolm, et al. (2000). A Review of Potential impacts on U.S. Terrestrial ecosystems and biodiversity. Ecosystems & Global Climate Change. Retrieved July 21, 2008 from http://www.pewclimate.org/doc/plocals/env_ecosystem.pdf.

McFadden, K. (2008). Lecture given on June 06, 2008 for the Environmental Science and Policy Masters in Public Administration Program at the School of International and Public Affairs, Columbia University.

Mendelsohn, R.(2000) Efficient Adaptation to Climate Change. Climate Change 45, 583-600.

New York City Department of Environmental Protection [NYC DEP]. (2007). New York City's Wastewater Treatment System. Retrieved July 16, 2008, from http://www.nyc.gov/html/dep/html/home/home.shtml.

NYC DEP. (2006). New York City 2005 Drinking Water Supply and Quality Report. Retrieved August 11, 2008, from. http://www.nyc.gov/html/dep/html/drinking_water/wsstate.shtml

O'Connor, A. & Bowley, G. (2007). Tornado Hits Brooklyn; Subway Back in Service. The New York Times, June 25, 2008. Retrieved August 11, 2008 from http://www.nytimes.com/2007/08/08/nyregion/08cnd-weather.html?_r=2&hp&oref=slogin&oref=slogin.

O'Flaherty, K. (2003) Local Government Salinity Initiative - Roads and Salinity, Department of Infrastructure, Planning and Natural Resources, Sydney, NSW, Australia. http://www.naturalresources.nsw.gov.au/salinity/pdf/booklet4.pdf.

Penland, S., & Suter, J. (1988) Barrier Island Erosion and Protection in Louisiana: A Coastal Geomorphological Perspective. Gulf Coast Association of Geological Societies Transactions. Vol. 38: 331-342.

Pew Center on Global Climate Change (2008) Climate Change 101: Adaptation. Retrieved August 11, 2008 from http://www.pewclimate.org/docUploads/Adaptation_0.pdf

PlaNYC 2030. (2008) The City of New York. Retrieved July 13, 2008 from http://www.nyc.gov/html/planyc2030/downloads/pdf/report_climate_change.pdf.

Rahman, S. (2007). Large Diameter PVC Pressure Pipe for Water and Sewer Applications in North America. Retrieved July 18, 2008, from www.pvc4pipes.org/documents/files/PXII/sess4a/Rahman.pdf.

Sander, E.G. Metropolitan Transportation Authority/New York City. (2007). August 8, 2007 Storm Report.

Third International Conference on Early Warning (EWC III). (2008) Retrieved July 10, 2008 from http://www.ewc3.org/.

Titus, J. G. (1998). Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches without Hurting Property Owners. Maryland Law Review, 57, 1279-1399.

Transportation Research Board (TRB). (2008). Potential Impacts of Climate Change on US Transportation.

US Environmental Protection Agency (EPA). (2007a). Climate Change - Health and Environmental Effects. Retrieved August 11, 2008, from http://www.epa.gov/climatechange/effects/energy.html.

EPA (2007b). Innovation and Research for Water Infrastructure for the 21st Century – Research Plan. Retrieved July 19, 2008, from www.epa.gov/awi/pubs/researchplan.pdf.

EPA (2007c). Science Brief – Aging Water Infrastructure Research Program: Rehabilitation of Wastewater Collection Systems. Retrieved July 17, 2008, from www.epa.gov/nrmrl/ppt/600f07012.pdf.

EPA (1995). America's wetlands: Our vital link between land and water. *Office of Water, Office of Wetlands, Oceans and Watersheds.* EPA843-K-95-001.

EPA (2004) Global Warming Publications, Sea Level Rise Reports. Retrieved August 11, 2008, from http://yosemite.epa.gov/oar/GlobalWarming.nsf/content/ResourceCenterPublicationsSeaLevelRiseIndex.html

Warren, L.P. (2007). *Scour at Bridges – What's it all about? Stream Stability and Scour Assessment at Bridges in Massachusetts?* United States Geological Survey Open-File Report 93–480. Retrieved June 24, 2008 from http://ma.water.usgs.gov/publications/ofr/scour.htm.

World Health Organization (WHO). (2008). Climate Change and Human Health. Retrieved August 11, 2008 from http://www.who.int/globalchange/climate/en/.