ClimAID Annex III

An Economic Analysis of Climate Change Impacts and Adaptations in New York State

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Executive Summary

This study provides an overview assessment of the potential economic costs of climate change impacts and adaptations to climate change in eight major economic sectors in New York State. These sectors, all of which are included in the ClimAID report are: water resources, ocean and coastal zones, ecosystems, agriculture, energy, transportation, communications, and public health. Without adaptation, climate change costs in New York State for the sectors analyzed in this report may approach $10 billion annually by midcentury. However, there is also a wide range of adaptations that, if skillfully chosen and scheduled, can markedly reduce the impacts of climate change by amounts in excess of their costs. This is likely to be even more true when non-economic objectives such as environment and equity are taken into account. New York State as a whole has significant resources and capacity for effective adaptation responses; however, given the costs of climate impacts and adaptations, it is important that the adaptation planning efforts that are now underway are continued and expanded.

Methods

The methodology for the study entails a six-step process that utilizes available economic data, interviews, and risk-based assessment to identify and where possible to assign costs of key sectoral vulnerabilities and adaptation options for climate change for eight economic sectors. The study draws conceptually from the general framework of benefit-cost analysis (recognizing its significant limitations in evaluating adaptation to climate change) to provide an overview assessment of the potential costs of key impacts and adaptation options. For all sectors, key economic components with significant potential impact and adaption costs are highlighted.

Sector Assessments

All of the eight sectors examined will have impacts from climate change, and for all sectors a range of adaptations is available. Because New York State is a coastal state and is highly developed, the largest direct impacts and costs are likely to be associated with coastal areas. Among the sectors in this study, these include the ocean coastal zone, transportation, energy and part of the water sector. However, impacts and costs will be significant throughout the state in sectors such as public health, transportation and agriculture. Impacts must be judged not only on the basis of direct economic costs, but also on the overall importance of sector elements to society. In terms of adaptation costs, the largest costs may be in the transportation sector, with significant adaptation costs for water, ocean coastal zones, energy, agriculture and ecosystems. The largest positive differences between benefits and costs among the sectors are likely to be in ecosystems and public health.

In addition to the overall analysis of the report, illustrative cost and benefit projections were made for one or more elements of the sectors. The results in terms of mid-century (2050s) annual costs (in $2010) of impacts are: water resources, $116-203 million; ocean coastal zones, $44-77 million; ecosystems, $375-525 million; agriculture, $140-289 million; energy, $36-73 million; transportation, $100-170 million; communications, $15-30 million, and public health

$2,998-6,098 million. These figures understate the aggregate expected costs, especially for heavily developed coastal areas, because they are for selected elements of the sectors for which extrapolations relating to climate data could be made. (Because of differences in method and data availability and the extent of coverage within sectors, these numbers are not directly comparable. For example, the high annual costs in public health are partly a function of the U.S. Environmental Protection Agency's estimate of the value of a statistical life (USEPA 2000; 2010.) The extent to which explicit public planning for adaptation will be required will differ among sectors: energy, communications and agriculture are sectors with regular reinvestment that has the effect of improving the resilience of the sector for present and future climate variability and other factors, and so climate adaptation will be more easily fit into the regular processes of these sectors. For the other sectors, much more public evaluation and planning will be required.

Overview assessments by sector are:

Water Resources. Water supply and wastewater treatment systems will be impacted throughout the state. Inland supplies will see more droughts and floods, and wastewater treatment plants located in coastal areas and riverine flood plains will have high potential costs of impacts and adaptations. Adaptations are available that will have sizable benefits in relation to their costs.

Coastal Zones. Coastal areas In New York State have the potential to incur very high economic damages from a changing climate due to the enhanced coastal flooding due to sea level rise and the development in the area with residential and commercial zones, transportation infrastructure (treated separately in this study), and other facilities. Adaptation costs for coastal areas are expected to be significant, but relatively low as compared to the potential benefits.

Transportation. The transportation sector may have the highest climate change impacts in New York State among the sectors studied, and also the highest adaptation costs. There will be effects throughout the state, but the primary impacts and costs will be in coastal areas where a significant amount of transportation infrastructure is located at or below the current sea level. Much of this infrastructure floods already, and rising sea levels and storm surge will introduce unacceptable levels of flooding and service outages in the future. The costs of adaptation are likely to be very large and continuing.

Agriculture. For the agriculture sector, appropriate adaptation measures can be expected to offset declines in milk production and crop yields. Although the costs of such measures will not be insignificant, they are likely to be manageable, particularly for larger farms that produce higher value agricultural products. Smaller farms, with less available capital, may have more difficulty with adaptation and may require some form of adaptation assistance. Expansion of agricultural extension services and additional monitoring of new pests, weeds and diseases will be necessary in order to facilitate adaptation in this sector.

Ecosystems. Climate change will have substantial impacts on ecosystems in New York State. For revenue-generating aspects of the sector, including winter tourism and recreational fishing, climate change may impose significant economic costs. For other facets of the sector, such as forest-related ecosystems services, heritage value of alpine forests, and habitat for endangered species, economic costs associated with climate change are more difficult to quantify. Options for adaptation are currently limited within the ecosystems sector and costs of adaptation are only beginning to be explored. Development of effective adaptation strategies for the ecosystems sector is an important priority.

Energy. The energy sector, like communications, is one in which there could be large costs from climate change if ongoing improvements in system reliability are not implemented as part of regular and substantial reinvestment. However, it is expected that regular investments in system reliability will be made, so that the incremental costs of adaptation for climate change will be moderate. Even with regular reinvestments there may be increased costs from climate change. Moreover, the energy sector is subject to game-changing policies and impacts such as changes in demand from a carbon tax (either directly or via cap and trade) and large investments in stability that could be undertaken to deal with the potential impacts of electromagnetic storms.

Communications. The communications sector is one in which there could be large costs from climate change if ongoing adaptations are not implemented as part of regular reinvestment in the sector or if storms are unexpectedly severe. However, it is expected that regular adaptations will be made, so that additional costs of adaptation for climate change will be relatively small.

Public Health. Public health will be impacted by climate change to the extent that costs could be large if ongoing adaptations to extreme events are not implemented. Costs could also be large if appropriate adaptations are not implemented in other sectors that directly affect public health, particularly water resources and energy. The costs associated with additional adaptations within the public health sector need further study.

The Future

This study is an important starting point for assessing the costs of climate change impacts and adaptations in New York. Much further work needs to be done in order to provide the extensive, detailed estimates of comprehensive costs and benefits associated with climate change required for planning. This work will have to deal with challenges such as the lack of climate-focused data sets and the fact that the feasibility of many potential adaptations has not been adequately analyzed. However, the basic conceptual approaches to future work have been identified, and even initial benefit-cost analyses of major impacts and corresponding adaptation options can help to illustrate the economic benefits of adaptation and thus to shape policy. This study therefore provides an important source of information for policy makers as to the relative size of climate impacts across major sectors of state activities and the adaptations that might be undertaken to deal with them. Because of the extensive impact and adaptation costs facing New York State, planning for adaptation to climate change must continue. With effective planning and implementation, the benefits from adaptation are likely to be significant because there are many opportunities for development of resilience in all sectors and regions.

1 Introduction

This study provides an overview assessment of the potential economic costs of impacts and adaptation to climate change in eight major economic sectors in New York State in the ClimAID report. The goal of the study is to provide information on the economic impacts of climate change and adaptation for use by public officials, policy makers, and members of the general public. The study is also intended to provide information that will assist the New York State Climate Action Council with identification and prioritization of adaptation areas for the state. While this study, because of limitations of data, case studies, methods and time, does not achieve the detail of the highly specific project evaluation that should be undertaken in the future in New York State, it nonetheless provides an important source of information for policy makers as to the relative size of climate impacts across major sectors of state activities and the adaptations that might be undertaken to deal with them. The state of the art of assessing the economic costs of climate impacts and adaptations is still nascent, so that this and other contemporary studies (cited throughout this report) perform important functions but cannot yet be considered as comprehensive.

The study draws from the information provided in the eight ClimAID sectors, supplemented by interviews with the sector leaders and other experts and by information from other studies of the costs of impacts and adaptation in New York State and elsewhere in the US and other countries. All these data sources are used to develop the information and assessments in the eight sector chapters in the report. Based on the study results, climate change costs, without adaptation, may approach $10 billion annually by mid-century for the sectors studied. However, there are a wide range of adaptations that, if skillfully chosen and scheduled, can markedly reduce the impacts of climate change in excess of their costs. This is likely to be even more true when non-economic objectives, such as the environment and equity, are taken into account.

This introductory chapter describes the framing approaches and methods of the study. Section 1.1 provides an overview of methods and some main results. Section 1.2 provides an overview of methodological concepts used in the study, including key terms and concepts, benefit-cost analysis, interest rates, the use of analogs, and the classification of impacts and adaptations. Section 1.3 describes the six steps used to develop the sectoral chapters and their results; and Section 1.4 is a summary of the methods used for the illustrative benefit-cost analyses.

Each of the eight sectoral chapters is organized according to the following pattern. The first part describes key economic risks and vulnerabilities and the illustrative benefit-cost analysis done for the sector. In the second part, the economic importance of the sector in New York State is described followed by a discussion of key climate sensitivities. Impact costs and adaptation costs are then examined from available information and additional information developed for the study, followed by a list of knowledge gaps for the sector. Technical notes describing the methods used in the benefit-cost analysis conclude each chapter. Consolidated references for the entire study follow the Conclusions chapter. Throughout the report, an attempt has been made to utilize stakeholder input of data, language and presentation, and to harmonize the work with the ClimAID chapters.

1.1 Summary of Methods and Main Results

The methodology for the study entails a six-step process that utilizes available economic data, interviews, and risk-based assessment (New York City Panel on Climate Change [NPCC] 2010) to identify and where possible to assign costs of key sectoral vulnerabilities and adaptation options for climate change in New York State. The study draws conceptually from the general framework of cost benefit analysis (recognizing its significant limitations in evaluating adaptation to climate change [Weitzman, 2009]) to provide an overview assessment of the potential costs of key impacts and adaptation options.

As part of the overall assessments for each sector, key economic components with significant potential costs were identified based on economic evaluation of the findings from the ClimAID sectors and the analyses of this study**.** Due to data limitations, costs could not be estimated for every component in each sector at this time. Table 1.1 presents a summary of the expected annual climate change impact costs at midcentury (i.e., for the 2050s) and the expected costs of adaptation options for the specified components of each sector, for which both impact and adaptation costs could be estimated. Details on the methods used to develop these extrapolations, and their limitations, are given in each specific sector chapter for the three study benchmark periods of the 2020s, 2050s, and 2080s.

A key issue for assigning costs of climate change is whether to focus on the effects of changes in the most damaging extreme events, such as coastal storms, or to focus on the changes in average climatic conditions. This study considers both of these types of climate changes. Estimates are made for costs and benefits with changes in extreme events for wastewater treatment plants, insured value for coastal zones, the transportation sector, energy, and health. The climate hazards include sea level rise, large coastal storms and heat waves. For agriculture and ecosystems, changes in the mean (average) value of climate variables are used. However, in all sectors broadly considered, both means and extremes matter.

Table 1.1 Available Estimated Annual Incremental Impact and Adaptation Costs of Climate Change at Mid-century for specified components of the ClimAID sectors. (Values in $2010 US.)

Sector	Component	Cost of annual incremental climate change impacts at mid-century for selected components, without adaptation	Costs and benefits of annual incremental climate change adaptations at mid-century for selected components
Water Resources	Flooding at Coastal Wastewater Treatment	$116-203 million	Costs: $47 million Benefits: $186 million
Coastal Zones	Insured losses	$44-77 million	Costs: $29 million Benefits: $116 million
Ecosystems	Recreation, tourism, and ecosystem service losses	$375-525 million	Costs: $32 million Benefits: $127 million
Agriculture	Dairy and crop losses	$140-289 million	Costs: $78 million Benefits: $347 million
Energy	Outages	$36-73 million	Costs: $19 million Benefits: $76 million
Transportation	Damage from 100 year storm	$100-170 million	Costs: $290 million Benefits: $1.16 billion
Communications	Damage from 100 year storm	$15-30 million	Costs: $12 million Benefits: $47 million
Public Health	Heat mortality and asthma hospitalization	$2.99-6.10 billion	Costs: $6 million Benefits: $1.64 billion
All Sectors	Total of Available Estimated Components	$3.8 – 7.5 billion/yr	Costs: $513 million/yr Benefits: $3.7 billion/yr

Note: see chapters for definitions of the selected components, and details of the estimation methods used. All values in $2010 US. The figures are not strictly additive because of the different methods used in each case

In each of the sector chapters, impacts and adaptations are evaluated according to four classes:

Level 1. Detailed assessment of costs for 2020s, 2050s, and 2080 where data permit (these are the components of the sectors that are represented in Table 1.1);

Level 2. Generalized estimates where data are limited. These estimates are based on literature and expert judgment;

Level 3. Qualitative discussion where cost data are lacking but there is general knowledge of impact and adaptation types;

Level 4. Identification of areas where costs are unknown because impacts and/or adaptation options are unknown or cannot be assigned.

An important strength of this and the ClimAID study is that the identification of economic risks and sensitivities to climate change is based on detailed, stakeholder-based investigation of specific sectors. Prior studies of the economic costs associated with climate change have generally entailed either top-down global assessments of impact costs (e.g., Stern 2007; Parry et al 2009), or highly generalized regional assessments for specific U.S. states that contain limited information on adaptation options (e.g. Niemi et al. 2009). This study of New York State provides an overview assessment of the costs of climate change impacts and adaptation that is grounded in empirical knowledge of key vulnerabilities and adaptation options.

The study of the economics of climate impacts and adaptations is relatively recent, so there are not enough examples of detailed studies, whether in New York State or elsewhere, to provide a wide assessment of costs. Further work needs to be done in order to fully estimate the comprehensive costs and benefits associated with climate change. This work will have to deal with challenges such as the lack of climate-focused data sets and the fact that the feasibility of many potential adaptations has not been adequately analyzed. On the other hand, the basic conceptual approaches to future work have been identified, and initial cost-benefit analyses of major impacts and corresponding adaptation options illustrate the economic benefits of adaptation.

1.2 Assessing the Economic Costs of Climate Change Impacts and Adaptation

The economic costs associated with both mitigation and adaptation to climate change are a topic of growing concern for national, state, and local governments throughout the world. Major research efforts to date, however, have primarily emphasized assessment of the aggregate costs of climate change impacts and adaptation at the global level across major country categories (e.g., developing countries), major world regions (e.g., Africa; South Asia), or specific sectors or countries, (e.g., World Bank 2006; Stern 2007; United Nations Framework Convention on Climate Change [UNFCCC] 2007; UNDP 2007; Cline 2007; Parry et al 2009). The estimates for the total costs of adaptation to the impacts of climate change are highly variable among these studies (see Agrawala and Fankhauser 2008). For example, estimates of the annual costs of adaptation in developing countries range from $10 to 40 billion/year (World Bank 2006) to $86 billion/year (UNDP 2007). The UNFCCC (2007) estimates of the annual global costs of adaptation in 2030 range between $44 billion and $166 billion. Reasons for this wide range of estimates include differences in how adaptation is defined, whether residual damages (see Table 1.2) are included in the estimates, and the comprehensiveness of the studies. A recent evaluation of the current state of knowledge for global adaptation cost estimates concluded that such estimates are preliminary and incomplete, and that important gaps and omissions remain (Fankhauser 2010, p. 25). Similar shortcomings are noted by Fankhauser (2010, p. 22) in studies conducted at the country level, particularly for estimates associated with National Adaptation Programmes of Action (see UNFCCC, n.d.), which also vary in scope, quality, and coverage. Despite limitations of both global and national studies, these studies nonetheless provide general guidance on the types of adaptations that may be needed within various sectors, as well as rough estimates of the types of costs that may be associated with these measures. A recent World Bank (2010) study uses an extrapolation framework similar to that used for the examples in Table 1.1.

While most prior work on adaptation costs has emphasized the global and national levels, several recent assessments of the costs associated with the impacts of climate change have been conducted for states including Washington, Maryland, and New Jersey (e.g., Niemi et al. 2009; CIER 2008; Solecki et al. 2011). These studies provide useful estimates of the general range of costs that may be associated with climate change impacts at a regional level. An important limitation of the existing state studies, however, is that these studies are not based on detailed climate hazard and vulnerability assessments, as have been conducted for the ClimAID project for each of eight major sectors. Many of the prior studies also lack detailed stakeholder-based considerations of adaptation options in the cost-benefit estimates.

In a few cases, estimates of the overall benefits of adaptation to climate change have been made. A leading example is in Parry et al. (2009, Ch. 8). Using runs of a simulation model, and the assumptions of the Stern Review (2007), the benefits of an invested dollar are estimated at $58. A more moderate estimate for adaptations to current variability in the United States (Multihazard Mitigation Council, 2005a) gives an overall estimate of $4 in benefits for each dollar invested in adaptation to current hazards. It can be expected that the benefits from adaptation will be significant in New York State. This is for two reasons: first, New York State is a coastal state, with enormous assets in the coastal counties that are at risk from sea level rise and storm surge; and, second, throughout the state, and not just in coastal areas, relatively little has been done by way of adaptation, so many favorable opportunities for adaptations with significant returns can be expected.

A third category of economic cost studies entails highly detailed analysis of one type of impact or adaptation option for a particular sector within a specific region. For example, a study by Scott et al. (2008) explores the potential costs associated with loss of snowpack in the Adirondacks for snow-dependent tourism industries in the region. These types of detailed studies, which are relatively scarce for New York State, help to inform estimates of the costs associated with specific impacts and adaptations in each sector.

Key terms and concepts

In discussing costs associated with impacts and adaptation to climate change, there are several types of costs that may be considered, as listed in Table 1.2. This study focuses primarily on identification of direct impact costs and direct adaptation costs (and benefits) (see Table 1.2).

Table 1.2. Defining different types of costs

Direct costs. The costs that are incurred as the direct economic outcome of a specific climate event or facet of change. Direct costs can be measured as by standard methods of national income accounting, including lost production and loss of value to consumers.
Indirect costs. The costs that are incurred as secondary outcomes of the direct costs of a specific event or facet of climate. For example, jobs lost in firms that provide inputs to a firm that is directly harmed by climate change.
Impact costs. The direct costs associated with the impacts of climate change (e.g., the reduction in milk produced by dairy cows due to heat stress higher mean temperatures and humidity under climate change.)
Adaptation costs. The direct costs associated with adapting to the impacts of climate change (e.g., the cost of cooling dairy barn to reduce heat stress on dairy cows).
Costs of residual damage. The direct costs of impacts that cannot be avoided through adaptation measures (e.g., reductions in milk production due to heat stress that may occur if cooling capacity is exceeded).

A discussion of adaptation costs, avoided damages, and residual damages both at a single point in time and over time is in Parry et al. (2009). In their discussion, these authors suggest that the costs of avoiding damage tend to increase in a non-linear fashion, becoming substantially higher depending on how much damage is avoided. Adaptation to the first 10% of damage will likely be disproportionately cheaper than adaptation to 90% of damage (Parry et al. 2009, p. 12). It is also important to recognize that while adaptation can reduce some damage, it is likely that damage will occur even with adaptation measures in place. This is particularly true over the long term, as both impacts and costs of adaptation increase.

Benefit-cost analysis, the statewide assessment and public policy

This study draws some insights from the approach of benefit-cost analysis, which has been developed over many years. The first use of the approach that required that project benefits exceed costs was embodied in the Flood Control Act of 1936 (United States Congress, 1936). Following World War II, standard economic benefit-cost analysis methods were developed and, by the early 1960s were widely accepted (Krutilla and Eckstein, 1958; Eckstein, 1958). This was followed by the development of methods for assessing non-economic as well as economic objectives (Maass et al., 1962; Marglin, 1967; Dasgupta et al., 1972; Major, 1977).

At the project level, benefit-cost analysis consists of identifying the stream of benefits and costs over time for each configuration of a project (such as a dam to control flooding), bringing these back to present value by means of an interest rate (discounting), and then choosing the project configuration that yields the maximum net benefits. This approach, widely used by the World Bank and other agencies for project analysis (Gittinger, 1972 is a classic World Bank example), embodies a range of (sometimes debatable) assumptions about the meaning of economic costs and benefits and the value of these over time (see Dasgupta et al., 1972 for an excellent evaluation of these issues). The benefit-cost approach has proven its utility as a framing method, and where benefit and cost estimates are good, relatively robust conclusions can be drawn about optimal project configuration, or, more specifically for the subject of this report, optimal adaptation design. On the other hand, the approach can be misused or used ineffectively; the quality of the work must be judged on a case-by-case basis. A further issue with benefit-cost analysis as usually employed is that it does not typically capture the sometimes extensive delays in design and implementation of measures in the public sector, which can lead to inappropriate choice of designs because projects are designed for the wrong level of climate change. Benefit-cost analysis has two roles in this study. First, the relatively few available benefit-cost studies are described in each of the chapters to help develop an overview of climate change impacts and adaptations in each sector. Second, the method is used as a framing device for the sectoral elements for which general estimates of future benefits and costs over the planning horizon can be made.

A more general issue is whether economic benefit-cost analysis should serve as the basis for public decisions in circumstances such as climate change in which potentially extreme outcomes are not captured by the method. Stern (2009, ch. 5) presents a carefully argued case for using ethical values beyond the market when dealing with climate change. Weitzman (2009) suggests (in response to Nordhaus 2009) that standard cost-benefit analyses of climate change are limited as guides for public policy because deep structural uncertainties about climate extremes render the technique inappropriate for decision-making. These uncertainties include: the implications of GHG concentrations of CO_2 outside of the long ice core record; the uncertainty of climate (temperature) sensitivity to unprecedented increases in CO_2; potential feedbacks exacerbating warming (e.g., release of methane in permafrost); and the uncertainty in extrapolating damages from warming from current information. Taken together, these factors suggest that although formal benefit-cost analysis can be helpful in some respects, it brings with it the danger of "undue reliance on subjective judgments about the probabilities and welfare impacts of extreme events" (Weitzman 2009, p. 15). While these arguments have typically been made at the global level, they are relevant for jurisdictions such as New York State that face potentially very large impacts from climate change; public decision-making efforts must go beyond the information presented in standard economic benefit-cost analysis.

At the same time, agencies should make use of the conceptual framework of benefit-cost analysis (for example in detailed studies comparing the cost of adaptations during the rehabilitation cycle with later stand-alone adaptations) where this approach is helpful. An example of adaptation relevant to New York State is the implementation of adaptations for wastewater treatment plants during rehabilitation, rather than the more expensive attempt to add on adaptations when climate change occurs. Appropriate studies for other issues can help substantially in determining how to schedule adaptations intended to achieve broad public policy goals; many such studies are needed.

Interest rates

In detailed studies, the interest rate is a key element in assessing future benefits and costs from climate change, because the present value of such effects can change greatly depending on the value of the interest rate. (The limitations of standard cost-benefit analysis for climate change have been addressed in significant part through discussions of the interest rate, i.e., the intertemporal weighting assigned to future events). There are advocates for low social rates of discount, most notably Stern (2007) as well as more standard opportunity cost rates (Nordhaus, 2007). Higher interest rates have the effect of postponing action on climate change, as future benefits are more heavily discounted. Stern (2009) argues persuasively that the risks of inaction are quite high (and largely uncertain or unknown), when compared to the costs of action (about 1-2% of GDP for several decades; Stern (2009, p. 90). The use of higher interest rates carries the implicit assumption that actions are reversible, which they are likely not to be in transformative conditions such as climate change.

A practical alternative for the interest rate currently available is for decision-makers to consider the consequences for decisions of using a range of interest rates from low to high. The Stern report uses very low interest rates—a range of 1-2%; market rates can range upward from 8% (Stern, 2007). In this report, interest rates are embodied in many of the available case studies. The estimates for elements of sectors use estimates of GDP growth rates, as discussed below in Section 1.4, but are not discounted back to the present. (The actual estimated values per benchmark year are given instead.) A recent report on the economics of adaptation to climate change suggests the use of sensitivity analysis on the interest rate (Margulis et al. 2008, p. 9). It is also important to note that while methods for integrating a social rate of discount (i.e. a socially-determined interest rate, rather than a market rate) with shadow pricing (an estimate of true opportunity cost) for private sector investments foregone have long been available (Dasgupta et al., 1972), shadow pricing has not been developed to confront the significant uncertainty of climate change.

Use of analogs

Ideally, a study such as this could provide a broad assessment of the costs of climate change impacts and adaptations based only on detailed studies in New York State. In fact, some examples of the economic costs of climate impacts and adaptations are available from cases in New York State, including a few cases in the main ClimAID report, and these are used where possible. However, because the detailed study of the economics of climate impacts and adaptations is relatively recent, there are not enough examples from New York State alone to provide a wide assessment of costs. Nonetheless, a larger range of examples of the economic costs of climate impacts and adaptations is available from other states, cities and countries. Some of these examples are relevant, and often quite analogous to, the types of climate change costs and adaptations that might be expected in New York State. Cost estimates from such cases are used in this study. In addition, there is another group of cases, both from New York State and elsewhere, that relate to adaptations to current climate variability rather than to climate change. These can often also be used to estimate costs for the same or analogous adaptations to climate change, and they are so used in this study as well. Both of these cases are representative of the "Value Transfer Method" (Costanza et al., 2006), in which values from other studies that are deemed appropriate are used for a new study. A further point is that processes for planning infrastructure are broadly the same across many sectors (Goodman and Hastak, 2006). By extension, information on planning climate change adaptations from one sector can be helpful in considering some elements of adaptation in other sectors.

Classifying impacts and adaptations

Thus, as part of the basis of the study, several classes of impacts and adaptations were reviewed and extended to the extent possible.

Impacts.

1. Impacts where good cost estimates exist, either in New York State or elsewhere;

2. Impacts where cost estimates can be obtained or extended within the resources of the project;

3. Impacts where cost estimates could be obtained with a reasonable expenditure of additional resources for new empirical analysis beyond the scope of this project. In such cases it is sometimes possible to describe the general size of costs; and

4. Impacts where it would be very difficult to estimate costs even with large expenditures of resources.

For some impacts, estimates can be made about the time period during which they will be felt, and thus some information is provided about the potential effects of discounting on these costs.

Adaptations. These can be specifically for climate change, but also can be for existing extreme events while being applicable to climate change.

1. Adaptations where good cost estimates exist, either in New York State or elsewhere. In some cases, benefits will be available as well;

2. Adaptations where cost estimates can be obtained within the resources of the project; in some cases benefit estimates can also be obtained;

3. Adaptations where cost estimates may be obtained with reasonable expenditure of resources for new analysis beyond the scope of this project. In such cases it is possible that the general size of costs can be described. This can sometimes also be true for benefits; and

4. Adaptations where it would be very difficult to estimate costs even with large expenditures of resources.

Adaptations can occur at any point over the time horizon of a project, and therefore their costs will also be subject to discounting. However, in many cases, adaptations will occur in the near term and therefore the effect of discounting will be relatively small, especially if low rates of interest are used.

As noted above, for each of the ClimAID sectors, a specific benefit-cost analysis is applied to a major sector element and a related adaptation strategy. For other impacts and adaptations, the extent to which examples of the eight cases described above have been found and analyzed is described in the chapter texts; where possible generalizations are made about the overall level of impact and adaptation costs and benefits for each sector.

1.3 Study Methods and Data Sources

The study design entailed six interrelated tasks. Each of these tasks was performed for each of the eight ClimAID sectors. The tasks entailed the following general sequence of activities:

Step 1: Identification of Key Economic Components

Drawing upon the sectoral knowledge and expertise of the ClimAID sector leaders and teams and recent studies of the economic costs of climate change (e.g., CIER 2007; Parry et al. 2009, Agrawala and Fankhauser 2008), this step entailed description of the major economic components of each ClimAID sector that are potentially vulnerable to the impacts of climate change (e.g., the built environment in the Ocean Coastal Zones sector). The information developed in this step is used to guide the remainder of the analysis for each sector.

Methods for this step included review of existing New York State economic data, compilation of data on economic value of the key components in each sector, and the use of a survey instrument developed for the research group's related study in New Jersey (Solecki et al., forthcoming) as the basis for interviews with sector leaders. The survey instrument includes questions about the key economic components of each sector and, for Steps 2-4 below, the sensitivity of those components to climate change and the potential costs associated with those sensitivities. Estimates of the value of production, employment, and/or assets in each sector were developed based on review of existing New York State economic data from the U.S. Economic Census, the Census of Agriculture, the Bureau of Economic Analysis, and other sources specific to each sector.

Step 2: Identification of Climate Impacts

Drawing upon on knowledge developed by the ClimAID sector team and other New York State experts, as well as current literature on the sectoral impacts of climate change (e.g., NPCC 2010 for infrastructure; Kirshen et al. (2006) and Kirshen (2007) for the Water Sector), the second step entailed identification of the facets of climate change (e.g., flood frequency, heat waves, sea level rise) that are likely to have significant impacts on the key economic components of each sector (as identified in Step 1). Methods used include developing a climate sensitivity list for each sector based on review of existing sectoral literature, New York State documents, ClimAID materials, results of interviews with ClimAID Sector Leaders (SLs), and consultation with ClimAID team members and other New York State experts.

Step 3: Assessment of Climate and Economic Sensitivity

The third step entailed further refinement of the climate sensitivity matrix developed for each sector in order to specify which climate-related changes identified in Step 2 will have the most significant potential costs for the key economic components of each sector. The step draws from the risk-based approach used in the NPCC (see Yohe and Leichenko 2010) to identify which economic components in each sector are most at risk from climate change (i.e., which components have highest value and/or largest probability of impact). In addition to results of the interviews as discussed above, this step also draws from the findings of NPCC (2010) and other relevant studies of the costs of adaptation to climate change (e.g., Parry et al. 2009; Agrawala and Fankhauser 2008).

Step 4: Assessment of Economic Impacts

This step entailed estimation, to the extent permitted by the available data, of the range and value of possible economic impacts based on the definition of the most important economic components and potential climate-related changes (Steps 1-3). Impacts are defined as direct costs that will be incurred as the result of climate change, assuming that the sector is operating in a "business as usual" frame and is not taking specific steps to adapt to climate change. Methods include evaluation of "bottom-up" results from ClimAID case study data where available, New York State economic data, and other economic data, and analysis of "top-down" data from the interviews with SLs and other experts. The estimates are quantitative where possible and qualitative where the data do not permit suitable quantitative estimates. The aim in both cases is to provide the best available information to decision makers. For each sector, available data is assessed for quality and comprehensiveness, supplemented where possible, and extended on an estimated basis to future time periods. In each case, costs for sector components are estimated and checked against other sources where possible. The uncertainties relating to the estimates are also discussed.

Step 5: Assessment of Adaptation Costs and Benefits

The next step entailed estimation of the costs and benefits of a range of adaptations based on the ClimAID sector reports and available case studies. The costs of adaptation are defined as the direct costs associated with implementing specific adaptation measures. Once adaptation measures are put into place, it is expected that some sectors will still incur some direct costs associated with climate change (i.e., residual damage). These costs are defined as the costs of impacts after adaptation measures have been implemented (see Table 1.2). The work in this step is framed using the standard concepts of benefit-cost analysis, with full recognition of the limitations of these techniques under the uncertainties inherent in climate change (Weitzman, 2009). This framework is combined with ideas of flexible adaptation pathways to emphasize the range of policy options available. Methods for this step include combining extrapolated case study information (see the next section) and results from interviews with SLs and other experts and identifying and assessing the relevance of other adaptation cost and benefit studies.

Step 6: Identification of Knowledge Gaps

The final step entails identification of gaps in knowledge and recommends further economic analyses, based on assessments of work in Steps 1-5.

1.4 Benefit-Cost Analyses Methods Summary

This study emerged based on a recognized need for additional information on the economic costs associated with climate change both in terms of the costs of the potential impacts and the costs and benefits of various adaptation strategies. The process described here provides a specific estimate of benefits and costs for a major component of each ClimAID sector as well as the broader-scale overview of economic impacts and costs of adaptations in each chapter. With the information from Steps 1-6, the general method to extrapolate costs and benefits used was first to identify current climate impact costs for a key component of each sector, and then to project these into the future, generally using a real growth rate for GDP of 2.4%. This value is a conservative estimate of the future long-term growth rate of the U.S. economy, which was 2.5% between 1990 and 2010 (see United States Department of Commerce, Bureau of Economic Analysis, n.d.). The estimate of 2.4% can be taken as a central tendency around which sensitivity analyses could be performed. It should be noted that this procedure does not capture possible climate feedbacks on GDP growth, nor does it take into account the potential impacts of climate change adaptation and mitigation efforts. Rather the approach provides general estimates of future costs without climate change based on reasonable assumptions applicable to each sector. Next, specific climate scenario elements from ClimAID are applied to estimate costs with climate change. Then, estimates of adaptation costs based on information in the text are made, as well as estimates of costs avoided (benefits).

This assessment takes into account in a broad way the with and without principle—identifying those sectors in which climate change adaptations are likely to be made as part of general sector reinvestment, whether or not there are specific adaptation programs in effect. Benefit estimates are from available literature on adaptation. The results are plausible scenarios that yield information on the magnitude of the figures involved, and that are reasonably resilient to changes in input assumptions. To illustrate the potential range of variation, key elements of the input assumptions have been varied, and the results are described in each chapter text.

While the economic costs estimates for impacts and adaptations are approximate, both because of data uncertainties and because they deal with future events, they nonetheless provide a useful starting point for prioritization of adaptation options in the state. The approach used represents a generalized framework that could be applied in a more comprehensive analysis. It should be recognized that the further out in time that the forecasts or extrapolations go, the less reliable they are. Other issues that impinge on the usefulness of these types of analytic tools in climate impact assessment include irreversibility, uncertainty (noted above in the discussion of benefit-cost analysis), and the associated possibility of non-linear or catastrophic changes. A further point is that the procedures used, tailored to each sector, differ, and thus the benefit and cost estimates for the various sectors are not strictly additive. Taken together, however, they give a general picture of the potential impacts and adaptation costs that New York State faces over the next century.

2 Water Resources

The water resources sector in New York State is an essential part of the economy and culture of the state. With its many outputs, such as water supply and flood control, and organizations both public and private, it is a complex sector. The principal impacts expected from climate change will be on various types of infrastructure that will be subject to increased risks from flooding as sea levels rise as well as significant impacts from droughts and inland flooding. These impacts, without adaptation, are likely to be at least in the tens of billions of dollars. There is a wide range of adaptations that is available in the water sector, including many that are contemplated now for current variability and dependability. The largest adaptation costs are likely to be those for wastewater treatment, water supply, and sewer systems.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR WATER RESOURCES

Key Economic Risks and Vulnerabilities

Of the many risks and vulnerabilities, the most economically important include the risks to coastal infrastructure, including wastewater treatment plants and water supply systems (ground and surface) from rising sea levels and associated storm surges. Inland flooding statewide is also an important economic risk; Figure 2.1 shows the location of some of the state's wastewater treatment plants within the current 100 year flood zone. Other economically important risks and vulnerabilities include the costs of droughts of potentially increased size and frequency, losses in hydropower production, and increased costs of water quality treatment. A loss of power can be costly in both economic and regulatory terms to water supply and wastewater treatment plants; on August 14, 2003, the blackout covering much of the Northeast caused shutdowns in the New York City Department of Environmental Protection's (NYCDEP) Red Hook and North River wastewater treatment plants, resulting in the discharge of untreated waters into New York Harbor. The resulting violations brought legal action by the United States Attorney's Office for the Southern District of New York (New York City Municipal Water Finance Authority [NYCMWFA], 2009, p. 54).

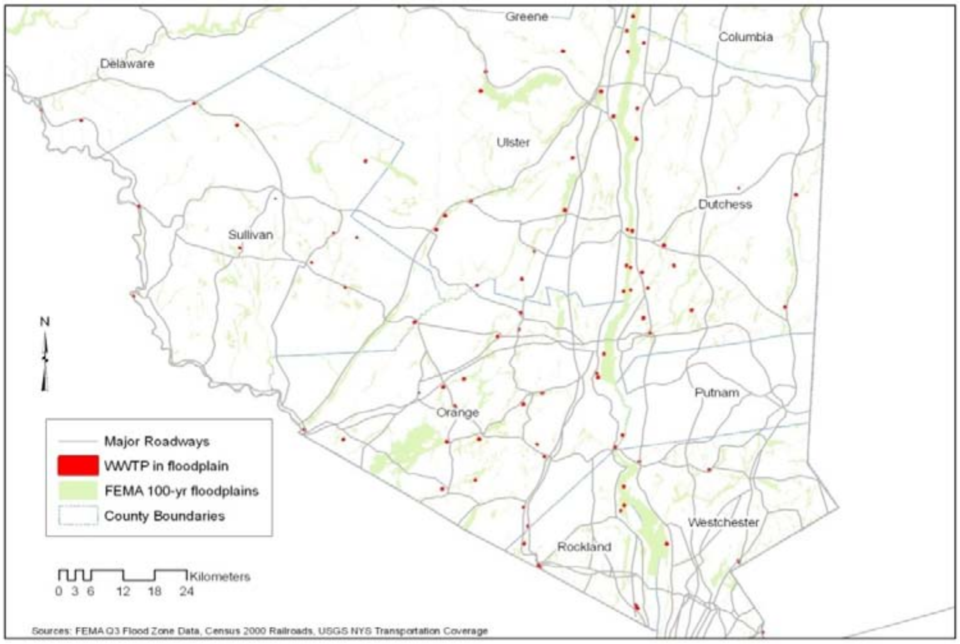

Figure 2.1. WWTPs in close proximity to floodplains in the Hudson Valley and Catskill Region. WWTPs along the Hudson are at risk from sea level rise and accompanying storm search.

One challenge in estimating future damages resulting from climate change is that the recurrence intervals of serious floods and droughts will become more difficult to estimate (Milly et al., 2008), and historical records will no longer be suitable as the sole basis for planning. The expected changes in the non-hydrologic drivers of floods and drought (e.g., development, population increases, and income growth) must also be taken into account.

The main relationships of climate and economic sensitivity in the water sector in New York State are shown in Table 2.1.

Table 2.1. Climate and Economic Sensitivity Matrix: Water Resources Sector (Values in $2010 US.)

Element	Main climate variables: Temperature	Main climate variables: Precipitation	Main climate variables: Extreme events: heat	Main climate variables: Sea level rise & storm surge	Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
Coastal flooding		●		●	– Damage to wastewater treatment plants – Blockage from SLR of system outfalls – Salt water intrusion into aquifers	Coastal flooding of WWTPs $116-203M	Costs: $47M Benefits: $186M
Inland flooding	●	●			– Increased runoff leading to water quality problems – Damage in inland infrastructure	High direct costs Statewide estimated $237M in 2010.	Restore natural flood area; decrease permeable surfaces; possible use of levees; control turbidity
Urban flooding		●			– Drainage system capacity exceeded; CSOs – Damage to infrastructure	Violation of standards	Very high costs of restructuring drainage systems
Droughts	●	●			– Reduction in available supplies to consumers – Loss of hydroelectric generation – Impacts on agricultural productivity	1960s drought in NYC system reduced surface safe yield from 1800 mgd to 1290 mgd	Increased redundancy and interconnectedness costs for irrigation equipment
Power outages	●	●	●		– Loss of functionality of wastewater treatment plants and other facilities	Violation of standards	Flood walls
Total estimated costs of key elements						$353-440M	Costs: $47M Benefits: $186M

(See Technical Notes at end of chapter for details. Total flooding costs are calculated minus an allowance for WWTP costs.)

Key for color-coding:

(dark blue)	**Analyzed example**
(medium blue)	**From literature**
(light blue)	**Qualitative information**
(white)	**Unknown**

The costs of climate change are expected to be substantial in the water sector, both for upland systems and for those parts of the system, such as drainage and wastewater treatment plants

(WWTPs), located near coastal area. An estimate for climate change impacts resulting from increased flooding of coastal WWTPs is given in Table 2.2; details of the calculation are in the technical notes at the end of this chapter. While these costs are expected to be significant, they will be just a part of total impacts costs for the water sector, which will be quite high. These costs will include the cost of infrastructure for improving system resilience and intersystem linkages, the costs of drought (both to consumers and water agencies), and the increased costs of maintaining water quality standards with changing temperature and precipitation patterns. Adaptation costs for the sector will also be higher than what is presented in the table and will include costs for adaptation of urban drainage and sewer systems, the costs of managing droughts, and the costs of preventing inland flooding. However, it is important to note that much of the drainage, wastewater and water supply infrastructure in New York is antiquated and inadequately maintained, with an estimated cost for upgrades of tens of billions of dollars. An important policy opportunity would be to use the need for infrastructure improvement as a simultaneous chance to adapt to anticipated climate change impacts, thereby reducing future risk and saving water currently lost through leaks or inefficient operations.

Table 2.2. Illustrative Key Impacts and Adaptations: Water Resources Sector (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)[1]	Annual incremental costs of climate change impacts, without adaptation ($M)[2]	Annual costs of adaptation ($M)[3]	Annual benefits of adaptation ($M)[4]
All New York State wastewater treatment plant damages from 100 year coastal event	Baseline	$100	-	-	-
	2020s	$143	$14-$43	$23	$91
	2050s	$291	$116-$203	$47	$186
	2080s	$592	$415-$533	$95	$379

[1] *Based on the most recent approximate 100 year WWTP flooding event (Nashville) and estimated repair costs, scaled up by population for New York City, Nassau, Suffolk, and 10% of Westchester (to represent lessened flooding risks there and up the Hudson). Growth in cost is scaled by US long term GDP growth of 2.4%.*

[2] *Ranges are based on changing flood recurrence intervals from NPCC (2010) p. 172.*

[3] *Costs are based on Rockaway WWTP total retrofit estimate, annualized and scaled up for New York City capacity and scaled up by Nassau, Suffolk and Westchester (10%) population.*

[4] *Benefits are based on the empirically-grounded benefit to cost ratio of 4:1 from Multihazard Mitigation Council (2005a) and the reference in Jacob et al. (forthcoming-a).*

Results
As the example of Table 2.2 indicates, costs of impacts may be large; adaptations are available, and their benefits may be substantial. While the numbers in the example depend on the input assumptions, within a fairly wide set of assumptions the magnitude will be in the same range. As other examples in the sector where climate change impacts are expected to be substantial, upstate WWTPs will be subject to flooding, and water supply systems will be subject to increased droughts as climate change progresses.

PART II. BACKGROUND

2.1 Water Resources in New York State
The water resource systems of New York State are many and complex, with a range of system outputs. These resources are abundant: New York State averages almost 40 inches of rain per year, and it is bordered by large fresh water lakes: Erie, Ontario, and Champlain. The outputs of New York State water systems include public water supply; industrial self-supply; cooling water for power plants; hydroelectric energy production; irrigation for agricultural and non-agricultural uses; dams for flood control; water-based recreation; flood control; water quality; wastewater treatment; instream flows for ecological systems preservation; and navigation. The sector has many components, reflecting the diversity of outputs: water supply utilities; wastewater treatment plants; agricultural and industry self-supply systems; hydroelectric generating stations; water-based recreation facilities; canals and navigable rivers; and wetlands and other ecological sites affected by water systems. The most important element of the sector to most citizens is probably public water supply. Schneider et al. (forthcoming) deals primarily with flooding, drinking water supply, water for commercial uses (mainly agriculture and hydropower), and water quality. This chapter uses examples from these and other system outputs.

Because of the number and variety of outputs of water systems, “water” is not a category in the North American Industrial Classification System (NAICS) (United States Bureau of Economic Analysis, n.d.); rather, the values of water system outputs are distributed among industries, utilities, government, transportation and others. Despite this diversity, the water sector has, particularly with regard to projects with Federal participation, a unifying factor: the application of multipurpose economic benefit-cost analysis. The water resources sector was among the first in which benefit-cost analysis was required (United States Congress, 1936), and relatively standard economic benefit-cost analysis methods had been developed by the early 1960s (Krutilla and Eckstein, 1958; Eckstein, 1958), followed by the development of methods for assessing non-economic as well as economic objectives (Maass et al., 1962). With this background, and because water systems deal with natural variability, there is a base of information that can be used to estimate more fully the impact and adaptation costs in the water sector brought about by a changing climate.

To focus just on water supply in the state’s large and complex water sector, the state’s water utilities vary widely in sources, public/private operations, and size. The largest in the state, the New York City Water Supply System (Figure 2.1), serves a population of more than 9 million people in New York City and upstate counties, nearly half of the state's population. The sources of supply are upland reservoirs in the Croton, Catskill, and Delaware Systems. The NYCDEP has already embarked on significant climate change activities (Rosenzweig et al., 2007b; NYCDEP, 2008). Other New York State utilities use a wide variety of sources: Poughkeepsie, drawing from the Hudson, Long Island utilities using groundwater; and Buffalo, drawing from Lake Erie. There are also many small suppliers in New York State, for which the New York Rural Water Association provides an umbrella organization. Some suppliers are public entities; others are private, and some public utilities have contracts with private water firms to manage their facilities. These New York State utilities face a wide variety of climate challenges, as exemplified in NPCC (2010). For all these reasons, New York State water utilities provide a range of challenges and opportunities in climate risk management. It is of interest that water resource utilities were among the first industries to be concerned with the impacts of climate change (Miller and Yates, 2005).

In addition to considerations of planning and management within the state, there are interstate and international institutional considerations affecting water supply in New York State, such as the Delaware River Basin Commission (DRBC) and the Great Lakes Basin Commission. Water utilities are regulated by a variety of laws and rules (Sussman and Major, 2010), including the Clean Water Act. While it is challenging to estimate the capital value of water utility infrastructure throughout the state, an idea of the size of this part of the sector can be gathered by considering that the NYCDEP's capital program for 2010 through 2019 is just over $14 billion (NYCMWFA, 2009, p. 24).

2.2 Key Climate Change Sensitivities

There is a very large range of potential impacts of climate change on the state's water resources from the principal climate drivers of rising temperatures, rising sea levels, higher storm surges, changing precipitation patterns, and changes in extreme events such as floods and droughts. These are described in detail in Schneider et al. (forthcoming); a comprehensive list for the nation as a whole is in Lettenmaier et al. (2008). Some of the most significant are presented in Table 2.3.

Table 2.3. Key Climate Change Sensitivities: Water Resources Sector

Impacts of rising sea levels, and the associated storm surges and flooding, on the water resources and water resources infrastructure in the state in coastal areas, including aquifers, wastewater treatment plants, and distribution systems.
Potentially more frequent and intense precipitation leading to inland flooding and more runoff and potential water quality problems in reservoirs.
Rising temperatures and potential changes in the distribution of precipitation leading to increases in the frequency and severity of droughts.
Potentially more intense precipitation events leading to increased urban flooding.
An intersectoral vulnerability is the loss of power, which shuts down pumping stations and wastewater treatment plants that do not have adequate back-up generation facilities.

2.3 Impact Costs

In estimating the costs of climate change in the water sector in New York State, relatively standard methods can be applied; however, data are often inadequate and the uncertainties in the future climate are large, compounded by uncertainties in other drivers such as population and real income growth. Nevertheless, in many cases costs or level of magnitude of costs have been estimated or could be obtained with reasonable additional effort.

As an example, the costs of sea level rise and storm surge on the water supply and wastewater treatment systems of Charlottetown, Prince Edward Island, have been estimated (McCulloch et al., 2002). Charlottetown, the provincial capital, has a population of some 32,000, and is therefore similar in size to many New York State coastal towns and smaller cities. A storm that generated a maximum height of 4.23 m above Chart Datum was used for the study. (The Chart Datum is the lowest theoretical astronomical tide at a site.) Under the hypothesized conditions, the replacement costs of the water, sanitary, and storm pipes, lift stations, sewage treatment plant and related infrastructure impacted were estimated to be $13.5 million Canadian (about $26 million US adjusted for inflation and exchange rates) (McCulloch et al., 2002). Because smaller coastal cities in New York State have similar infrastructure at low elevations, this suggests large climate impacts in the aggregate for coastal municipal water supply systems in New York State, bolstering the example in Table 2.2.

There are potential impacts of climate change on water resources in New York State that could be substantially larger. Very significant cost impacts on wastewater treatment plants and sewer system outfalls can be expected as sea level rises. Sea level rise will cause the salt water front in the Hudson to move northward; under some scenarios, this would require the repositioning of the intakes for the City's Chelsea Pump Station and the Poughkeepsie water supply system. (Cost estimates for these impacts are not available.) In the Delaware, there could be substantial institutional and operating costs relating to the integrated operation of the river with the New York City water supply system, which releases specified flows to the river from its Delaware watershed reservoirs (Major and Goldberg, 2001) which might have to be modified over time as new infrastructure came on line for Philadelphia. (This could potentially include complex legal issues, as flows are currently regulated by U.S. Supreme Court rulings.)

Other impact costs will relate to precipitation changes and increased evapotranspiration that can lead both to more intense precipitation and more droughts. More intense precipitation could bring about increased turbidity in New York City's watersheds. In this case, turbidity control measures could be brought to bear, for example utilizing the Croton System more effectively to minimize use of the Catskill System during turbidity events. With respect to droughts, should droughts increase in frequency and intensity toward the end of the century, as is widely expected, costs could reach significant amounts both for losses to water system consumers and for emergency measures. Estimating the current value of such impacts is challenging. The recurrence intervals of the drought of record and more serious droughts are difficult to estimate, given both the loss of stationarity incumbent upon climate change, and the expected changes in the non-hydrologic drivers of population and income growth. Droughts will impact the availability of water for a variety of sectors including household supply, including irrigation for agriculture.

Another impact of precipitation changes could be increased inland flooding of towns, cities, and other areas. Considering just the issue of wastewater treatment, many of the state's wastewater treatment plants are located in areas subject to inland flooding (Figure 2.1). As for damages to all sectors in one basin, flooding in 2006 in the Susquehanna Basin caused estimated damages of $54 million (Schneider et al. (forthcoming). Interpreting this figure, the estimate may be too low for future storms if these become more frequent and/or intense; the additional costs would be attributable to climate change. In addition, asset values may increase over time, which will increase the costs of such climate-related precipitation changes.

A cost estimate for flooding in a neighboring state is of interest in this regard. In 1999, there was an estimated $80 million in damages from flooding in the Green Brook sub-basin of the Raritan. This sub-basin is continually subject to severe and sometimes devastating flood damage (United States Army Corps of Engineers [USACE], n.d.). If there are more frequent and intense rainfall events with climate change, as many observers expect, such damages will be larger and/or occur more frequently and will therefore be an economic consequence of climate change. While the aggregate future dollar values have not been estimated, is seems clear that flooding impacts from climate change in New York, as in its neighbors, could be quite large.

2.4 Adaptation Costs

There is a wide range of potential adaptations to the impacts of climate change on water resource systems; these can be divided into adaptations for: management and operations; infrastructure investment; and policy. Adaptations can also be classified as short-, medium- and long-term. Costs vary substantially among different types of adaptations; and the adaptations need to be staged, and integrated with the capital replacement and rehabilitation cycles (Major and O'Grady, 2010). There has begun to be a substantial number of studies of estimating the costs of adaptations, and in some cases, cost estimates (Parry et al. 2009; Agrawala and Fankhauser, eds., 2008). Several adaptations have been estimated that relate to climate change. As one example relating to planning and research as components of adaptation to climate change, the NYCDEP's study of the impacts of climate change on its facilities (NYCDEP, 2008b) is expected to cost less than $4 million but at least several million dollars. A second research adaptation to climate that is already in place in NYCDEP is the use of future climate scenarios to study potential needed changes in system operation, using the Department's reservoir operating models (NPCC, 2010, App. B). The costs of a series of model runs over an extended period can be approximated by the cost of a single post-doc employee at NYCDEP hired through a major research university for one year. In 2010, such an employee would be paid $55K, and with benefits and overhead at typical levels the total would be $92K.

Costs for capital adaptations are of course much greater than costs for research and planning. The costs of raising key equipment at the Rockaway Wastewater Treatment Plant are estimated at $30 million; this is an adaptation that will help both with current variability and future sea level rise. Total adaptation costs for coastal wastewater treatment plants and low-lying parts of the water supply and sewer systems are likely to be very large. In addition to the climate change study referenced above, which has not yet begun, the NYCDEP has underway its Dependability Study (NYCDEP, 2008a), which is designed to provide for continuity of service in the event of outage of any component, is considering among other possibilities interconnections with other jurisdictions; increased use of groundwater supplies; increased storage at existing reservoirs; withdrawals and treatment from other surface waters; hydraulic improvement to existing aqueducts and additional tunnels (NYCMWFA, 2009, p. 48). All of these measures, for many of which costs are in process of being estimated, would also be suitable candidate adaptations to climate change. The climate change and Dependability studies together will provide a good basis for estimates of adaptation to climate change in the New York City Water Supply System.

A drought emergency measure for which costs could be re-estimated is the cost of the pipe laid across the George Washington Bridge in 1981 to allow New York City to meet some of its Delaware obligations from its east-of-Hudson watershed (Major and Goldberg, 2001). (A recent search of NYCDEP records was unsuccessful in finding the original costs.) This drought adaptation was explicitly authorized by the Delaware River Basin Commission, and although never used, could be replicated today in appropriate conditions. There is a range of other actual and potential adaptations for which costs have not yet been estimated but for which costs could be estimated from existing information and reasonable forecasts; this is work that should be undertaken in the near future.

The proposed costs for adaptation to current conditions in the Green Brook NJ case are of interest to New York State because the Green Brook area is highly developed, as is the case with some New York State inland riverine areas, and therefore flood characteristics are partly human-created. The United States Army Corps of Engineers (USACE) is planning to spend, including local contributions, $362 million over 10 years to build levees/floodwalls, bridge/road modifications, channel modifications, closure structures, dry detention basins, flood proofing and pump stations in Green Brook (USACE, n.d.). The estimated benefit-cost ratio for this work is 1.2:1. The plan is designed to deal with floods up to the current 150 year recurrence interval in the lower basin and the current 25 year recurrence interval in the upper basin, so that expected damages from floods within these recurrence intervals would be expected to decrease (USACE, n.d.). However, the recurrence intervals of the given floods may be reduced (the floods became more frequent) with climate change, and their intensity may also increase, thus offsetting some of the effects of the proposed adaptations.

2.5 Summary and Knowledge Gaps

From the standpoint of improving the ability of planners to do economic analysis of the costs of impacts and adaptations in the transportation sector, there are many knowledge gaps to which resources can be directed. These include:

- A comprehensive data set in GIS or CAD form of as-located elevations of water system infrastructure

- Updating of FEMA and other flood maps to reflect the impacts of rising sea levels.

- Undertaking of a series of comprehensive benefit-cost analysis of potential adaptations to aid in long term planning, building upon current studies of the NYC system and other systems.

- Developing a comprehensive data base, GIS referenced, on the condition of water infrastructure projects across the state, including wastewater treatment plants, CSOs, and water supply systems which could be used to prioritize and allocate climate adaptation funding as it becomes available.

- Integration of population projections into climate change planning.

- More advanced planning for power outages and their impacts on wastewater treatment plants and other facilities.

Technical Notes – Water Resources Sector

Water extrapolation methods for the text example:

1. The initial annual cost is based on the most recent approximately 100 year event that flooded a WWTP, in Nashville in 2010. The estimated repair costs for the Dry Creek plant are $100 million; the population served by the Dry Creek plant is 112,000 (Nashville Water Services Department, personal communication).

2. These costs were scaled up by population for NYC, Nassau, Suffolk and 10% of Westchester. This gives total costs of 10$B, or annual costs of $100 million over 100 years. Scaling by population rather than number of plants gives a more general estimate of costs.

3. This figure is then extrapolated assuming a US GDP real growth rate of 2.4%.

4. The range of flood recurrence with SLR is then applied to yield the increase in damages; these ranges are based on NPCC (2010), p. 177. Flood damages (because of SLR) become about 10% more frequent in the 2020s, 40% more frequent in the 2050s, and 70% more frequent in the 2080s (NPCC 2010) for the low estimate of SLR, and become about 30% more frequent in the 2020s, 70% more frequent in the 2050s, and 90% more frequent in the 2080s (NPCC 2010) for the low estimate of SLR.

5. To prepare for climate change—and growth—NYC is spending $30 million to raise pumps and other electrical equipment at the Rockaway WWTP plant well above sea level. These costs are used for adaptation costs in the example, annualized and scaled up by capacity for NYC and by population for Nassau and Suffolk and 10% of Westchester.

6. Reductions in impacts (benefits from adaptations) are estimated using the empirically determined 4:1 benefit to cost estimate (from the references in Jacob et al. (forthcoming-a), which is appropriate for infrastructure-intensive sectors.

7. For Table 3.1, the estimated total flooding in the state, estimated at $100 million in $US 2009, is assumed to grow at an annual rate of GDP (2.4%). It is assumed conservatively that 80% of this is unrelated to WWTP flooding, and thus the figures are assumed to be additive.

3 Ocean Coastal Zones

The ocean coastal zone in New York State is an essential part of the economy and culture of the state; with its many economic and natural outputs and governing organizations, it is a complex system. Total losses from climate change on coastal areas (without further adaptation, and excepting transportation, discussed in the Transportation chapter of this report), over the next century will be in the hundreds of billions of dollars, primarily from rising sea levels and the associated higher storm surges and flooding. Adaptations are available to reduce some of these impacts; their costs may be in the tens of billions of dollars, and they will need to be carefully scheduled over the course of the century for maximum effectiveness and efficiency.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR COASTAL ZONES

Key Economic Risks and Vulnerabilities

Of the many risks and vulnerabilities, the most economically important are the multifaceted risks to coastal zones from higher sea levels and consequent higher storm surges. Substantial economic losses can be expected in buildings, infrastructure, natural areas, and recreation sites. Other impacts from precipitation changes, higher temperatures, higher ocean temperatures and ocean acidification will also have significant impacts. Table 3.1 provides a summary of climate and economic impact categories. The negatives shown substantially outweigh the positives.

Table 3.1. Climate and Economic Sensitivity Matrix: Ocean Coastal Zones Sector (Values in $2010 US.)

Element	Main Climate Variables: Temperature	Main Climate Variables: Precipitation	Main Climate Variables: Sea Level Rise & Storm Surge	Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
Coastal Flooding (Insured damages)			●	– Significant damage to buildings, transportation, other infrastructure and natural and recreation areas	$44-77M	Costs: $29M Benefits: $116M
Inland flooding and wind damage in coastal areas		●		– Damage from more intense and frequent precipitation events	Comparable to coastal flooding	Emergency evacuation procedures
Salt front			●	– Salt front moving further up the Hudson – Impacts on water intakes – Impacts on natural areas	Moderate costs for water supply; significant impacts on natural areas	Relocation of intakes
Marine ecosystems	●	●	●	– Impacts from higher ocean temperatures – Impacts from increased ocean acidity	Unknown	Need for additional research; global mitigation efforts required
Recreation	●		●	– Loss of some recreation areas + Longer warm season for some types of recreation	Annual cost of loss of 10% of beach area in Nassau/Suffolk estimated as $345M	Beach nourishment
Freshwater sources	●	●	●	– Potential salt water intrusion into aquifers – Water quality problems from heat and turbidity	Unknown	Turbidity management measures
Natural areas	●	●	●	– Recession of wetlands from sea level rise – Damage from more intense storms – Ecosystem changes from heat – Beach and bluff erosion	$49M annually for loss of 10% of natural areas	Mitigation and retreat
Total costs of estimated elements					$416-449	Costs: $29M Benefits: $116M

(See technical notes at the end of the chapter for details of calculations)

Key for color-coding:

	Analyzed example
	From literature
	Qualitative information
	Unknown

The expected costs of climate change on coastal zones in New York State are expected to be very large. An estimate based on extrapolation of insured damages for New York State coastal zone is presented in Table 3.2, with details on methods in the technical notes included in this section. While there are other significant damages, including damages from winds and inland floods, uninsured damages, and damages to self-insured public infrastructure, insured damages are a substantial element in total sector damages.

Table 3.2. Illustrative Key Impacts and Adaptations: Ocean and Coastal Zones Sector (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)[1]	Annual incremental costs of climate change impacts without adaptation ($M)[2]	Annual costs of adaptation ($M)[3]	Annual benefits of adaptation ($M)[4]
Coastal flooding insured damages[5]	Baseline	$38	-	$10	-
	2020s	$54	$5-$16	$14	$57
	2050s	$110	$44-$77	$29	$116
	2080s	$225	$157-$202	$59	$237

[1] *See the technical notes for the estimation of the baseline and future impacts from insured damages information*
[2] *Based on increased frequency of coastal floods (NPCC,2010, p. 177) for range of climate scenarios*
[3] *Based on potential annual expenditures for building elevation, sea walls, emergency planning, beach nourishment and wetlands management estimated from case studies in the Coastal Zone text, especially Tables 3.6 and 3.7. The total of $10 million is based on the following figures (in millions): building elevation, 2; sea walls 2; emergency management 1; beach nourishment 2; and wetlands management 1. The total assumes no surge barrier construction within the scenario time frame.*
[4] *Based on the empirical 4:1 benefit to cost relationship from Jacob et al. (forthcoming-a) references. Rounding in the calculations results in this relationship being approximate in the table.*
[5] *Insured damages in the example include losses to property from coastal flooding, and in some cases, business interruption losses.*

Results

As the example in Table 3.2 indicates, costs of impacts may be large; adaptations are available, and their benefits may be substantial. While the numbers in the example depend on the input assumptions, within a fairly wide set of assumptions, the magnitude will be in the same range. Furthermore, most public infrastructure, such as the New York City subway system, bridges, and tunnels, is self-insured, so that while it is not included in the insured estimates used for the example the loss potential is large. In addition, although smaller in dollar terms, impacts on natural areas will be substantial.

PART II. BACKGROUND

3.1 The Ocean Coastal Zone in New York State

The ocean coastal zone of New York State comprises parts of the 5 counties of New York City, Nassau, Suffolk and Westchester counties, as well as the counties bordering the Hudson River to Troy Dam, since these too will be impacted by sea level rise. The characteristics of the coastal zone in New York State are very varied. The most striking element is the high level of urban development along the coast in New York City, but there are also many natural coastal features, including coastal and marine ecosystems, beaches, and bluffs. Most of these areas are open to the ocean; in the Hudson Valley, much of the original shoreline has been engineered for railways and other purposes (Buonaiuto et al., forthcoming). Because of the wide range of coastal systems, both impacts and adaptations will vary geographically in the New York State coastal zone. Due to the number and variety of elements in the ocean coastal zone, this sector of ClimAID is not a category in the North American Industrial Classification System (NAICS) (U.S. Bureau of Economic Analysis, n.d.). The values produced by economic activity in the ocean and coastal sector are distributed among a wide variety of industry, government, commercial and private activities. However, a simple metric of economic worth is the total insured value in coastal counties in New York State in 2004. This was nearly 2 trillion dollars: $1,901.6 billion, or 61% of the total insured value in New York State of $3123.6 billion (AIR Worldwide Corporation, 2005). (AIR (2007) reported and estimated $2,378.9 billion of insured coastal exposure in New York State.)

3.2 Key Climate Change Sensitivities

There is a very large range of potential impacts of climate change on the state's ocean coastal zone from the principal climate drivers of rising sea levels, higher storm surges, rising temperatures, changing precipitation patterns, and changes in extreme events such as floods and droughts. Some of the most significant are presented in Table 3.3.

Table 3.3. Key Climate Change Sensitivities: Ocean Coastal Zones Sector

Rising sea levels and the associated storm surges and flooding will impact all coastal areas, including buildings, transportation and other infrastructure, recreation sites and natural areas.
Potentially more frequent and intense precipitation events will cause more inland flooding in coastal areas.
Rising temperatures and potential changes in the distribution of precipitation will impact natural areas.
Higher temperatures will change the use and seasons of recreation areas.
Movement of the salt front up the Hudson as a result of sea level rise will impact both natural areas and water intakes.
Sea level rise may degrade freshwater sources, infrastructure and other facilities through salt water intrusion.
Sea level rise and storm surge will cause beach erosion.
Sea level rise and storm surge will cause bluff and wetland recession.
Rising ocean temperatures will impact marine ecosystems.
Increased ocean acidity will impact marine life.

3.3 Impact Costs

In estimating the costs of climate change on the ocean coastal zone in New York State, relatively standard methods can be applied; however, data are often inadequate and the uncertainties in the future climate are large, compounded by uncertainties in other drivers such as population and real income growth. Nevertheless, in many cases costs or level of magnitude of costs have been estimated.

One approach to estimating the size of impacts of climate change on coastal counties, largely relating to the built environment, is to consider insured losses from storms in New York State. Insured losses for all natural and man-made catastrophic events in the United States are available from Property Claims Services (PCS), a division of Insurance Services Offices, located in Jersey City, NJ. The PCS database covers from 1950 to present day, and insured market losses are available by state, by event and by year. Available in event-year dollars, the insured losses are brought to as-if estimates by assuming a compound annual growth rate of 6.75%.

The three weather perils which drive insured losses in New York State are winter storms (both lake-effect events and nor'easters are included in this category), hurricanes and severe thunderstorms. Nor'easters and hurricanes have the largest impact on coastal regions, while other winter storms and thunderstorms are prevalent throughout the state. Nor'easters/winter storms contribute the most to both annual aggregate losses and event-based losses in New York State; nor'easters can cripple the NYC metro area and significant lake-effect snow events can be highly problematic for Syracuse, Buffalo and Rochester. Due to their infrequent occurrence, hurricanes do not contribute significantly to annual aggregate losses, but do have high event-based losses. The opposite is true with severe thunderstorms; the event-based insured losses caused by severe thunderstorms are not often substantial, but the losses can accrue to a significant amount on an annual basis.

Since 1990, ten years have seen annual aggregate as-if losses in excess of $500 million US. With over $1 billion dollars (2010 as-if) in insured losses, 1992, which featured the December '92 nor'easter, was the costliest year in terms of natural catastrophe loss. Future losses can certainly exceed the historical losses of the most recent 20 years. For example, Pielke et al. (2008, p. 35) adjusted the losses from the 1938 hurricane to account for inflation, changes in population density (and thus exposures) and asset value, and estimated that the 1938 storm, if it occurred today, would cause $39.2 billion (2005 $US) in economic damages.

This information gives insight into the magnitude of potential insured losses from climate events without further adaptation measures. As sea level rises, the probability of any given amount of flooding rises. For example, the same event that causes a 25-year flood today might produce a 10-year flood later in the 20th century when the storm surge impacts are compounded by increased sea level. The incremental increases in flooding and damages at each level (adjusted for population and development changes unrelated to climate change) are therefore attributable to climate change. For example, if the flooding levels from the 1992 storm were replicated once over the coming century, the amount attributable to climate change would be the damages from that storm minus the damages that would have occurred absent SLR. When summed over all storms, this number will be quite large during the coming century, almost certainly in the tens of billion dollars and quite possibly in the hundreds of billion dollars. This number is an estimate of the impacts of storm flooding, and does not consider permanent losses from sea level rise, which will also be very significant.

This approach is useful for the general size of impacts. However, the use of insured loss figures has some limitations that prevent their use as complete estimates of impact. Primarily, the insured loss figures understate total losses because of the substantial amount of uninsured properties and self-insured facilities such as subways, bridges, tunnels, recreation areas, and natural areas. There are also institutional complications that will affect the values of insured property in the future. For example, the federally mandated U.S. National Flood Insurance Program is active in New York. Any residence with a mortgage backed by a federally regulated or insured lender located a in high-risk flood area, defined as an area within the 100 year flood plain, is required to have flood insurance. Homes and businesses located outside the 100-year flood plain are typically not required to have insurance (http://www.floodsmart.gov). The average flood insurance policy costs less than $570/year (http://www.floodsmart.gov), which is regarded as well below a true actuarially based risk premium. Many analysts feel that NFIP (due for reauthorization on September 30, 2011) is unsustainable over the long run, and in the event of a large loss, many insured parties will not be able to receive a payout and the financial burden is then transferred to the tax payers. Many private insurers do not offer personal line flood insurance because they are not able to charge the true rate that would be required.

Another approach to the size of impacts of climate change in the New York State ocean coastal sector relates to ecosystem services, focusing more on natural areas or human-affected natural systems, rather than on the built environment. (This is a subject that overlaps with the analysis of Chapter 4, Ecosystems.) A range of estimates for per-acre annual ecosystem services for different types of ecosystems has been developed for New Jersey (Costanza et al., 2006). Several different approaches to valuation were used; the figures cited here are the so-called "Value Transfer Method" figures, which are essentially figures from existing studies of some relevance to New Jersey. They are relevant to New York also because of the similarity of many coastal zone ecosystems in the two states. The figures used here are from "Type A" studies, the best attested, from either peer-reviewed journal articles or book chapters. Each type of ecosystem has different services. Beaches, for example, are credited with disturbance regulation (buffering from wave action and other effects), esthetic and recreational values, and a smaller component of spiritual and cultural value. For the sum of these services, in $2004, the study gives an annual value of $42,127 per acre per year averaged over the available Type A studies. Salt water wetlands, with services including disturbance regulation, waste treatment, habitat/refugia, esthetic and recreational, and cultural and spiritual, have an average estimated value per acre per year of $6,527. These values should be reasonably applicable to New York State coastal zones, although in order to make firm estimates a wide range of assumptions would have to be examined. To examine impacts (losses of ecosystems and their services) from climate change, the total number of acres estimated to be lost in each category over the coming century would be estimated using flood mapping and other techniques. These and other coastal ecosystem estimates per acre per year are given in Table 3.4 (from Costanza et al. (2006, p. 17).

Table 3.4. Summary of average annual value of ecosystem services per acre for New Jersey, $2004

Coastal Shelf	$620
Beach	$42,147
Estuary	$715
Saltwater Wetland	$6,527

Source: Costanza et al. 2006

The totals for beach losses would be expected to be quite high for New York State coastal zones over the coming century. While of course not all acres would be affected, it is of interest that in 2006 it was estimated that there were 24,320 acres of beach and dune in Nassau and Suffolk Counties, and, from the only available but outdated (and thus probably high) estimates, 23,578 acres of tidal marsh in these two counties (Table 3.4). The estimated costs of losing 10% of each type of ocean landscape using the Costanza et al. (2006) estimates are $102.5 million (2004) year and $15.4 million (2004) year. A project underway by The Nature Conservancy (www.coastalresilience.org) has developed and is now applying a coastal mapping tool that will enable the detailed estimation of losses of coastal landscapes from sea level rise and storm surge over the course of the century for southern Long Island and Long Island Sound.

Table 3.5. Estimated Beach/Dune and Tidal Marsh Acres in Nassau and Suffolk Counties and Impacts of Loss of 10% of Acres

County	Est. Beach/Dune Acres 2006	Est. Tidal Marsh Acres 1974
Nassau	3,420	9,655
Suffolk	20,900	13,923
Totals	24,320	23,578
Annual $2004 impact of losing 10% of estimated acreage	$102.5 million	$15.4 million

Sources: 2006 Beach/Dune, The Nature Conservancy, n.d.; 1974 Tidal Marsh, New York State Department of Environmental Conservation, 1974; loss estimates/acre/year Costanza et al., 2006.

3.4 Adaptation Costs

There is a wide range of potential adaptations to the impacts of climate change on the New York State coastal zone; these can be divided into adaptations for: management and operations; infrastructure investment; and policy. Adaptations can also be classified as short-, medium- and long-term. Costs vary substantially among different types of adaptations; the adaptations need to be staged, and integrated with the capital replacement and rehabilitation cycles (Major and O'Grady, 2010). There has begun to be a substantial number of studies about how to estimate the costs of adaptations, and in some cases, cost estimates (Parry et al. 2009; Agrawala and Fankhauser, eds., 2008). Several adaptations have been estimated that relate to climate change. For coastal zone climate impacts, there will be some losses (e.g. some natural areas) that are essentially unpreventable; for many other losses, some appropriate menu of adaptations that varies over time can be developed. Some of these adaptations for either or both of climate change and current variability are given here, with the figures summarized in Table 3.6.

- Emergency evacuation planning is an emergency management/operations measure that is already in place for current climate variability. The costs of improving this program over time as SLR rises will be relatively small, although they have not yet been estimated, and the benefits are potentially large.

- Some infrastructure costs can be modest. As an example of an adaptation to a long-standing problem with a salt marsh, the separation of a salt marsh on the Connecticut shore of Long Island Sound from the Sound by development is presented in Zentner et al. (2003). The estimated costs/acre for a 10 acre salt marsh where a dike has been breached range from $6,000 to $14,100 depending on the nature of the levees that are constructed to improve the flow of salt water from the sound to the marsh (Zentner et al., 2003, p. 169). This is an example of a type of adjustment for a marsh that could be relevant to some marshes as the sea rises, and is directly relevant to New York State salt marshes, at least those on LI Sound.

- On the other hand, estimates for some wetlands restoration are substantially higher. Like beach nourishment (below), such costs may be more appropriate for the earlier part of the century than later, especially for wetlands that have no retreat route. Estimates from a personal communication (Frank Buonaiuto), suggest a wide variation. In the mid range is the cost of recreating the marsh islands of Jamaica Bay-Elders West, about $10 million for 40 acres ($250,000/acre); for a project at Soundview, including excavation costs, the total would be about $5 million for 4 acres, or $1.25 million/acre.

- An example of adjustment to storms that involves a moderately expensive capital investment for sea walls and other facilities is the proposal for Roosevelt Island in New York City set out by the USACE in its Roosevelt Island Seawall Study and announced by Congresswoman Maloney (Maloney, 2001). The study advocated wall repair (rather than wall replacement that could cost 10 times as much) for the existing seawall, noting particular concern for the northwest shoreline and the eastern sections adjacent to an underground steam tunnel. The estimated cost for this repair work was $2,582,000. Besides repair work, the USACE recommended further testing of the walls and the establishment of a design/maintenance standard for the seawall. To protect the southern shoreline from storms and erosion, the study finds a vinyl sheet pile (a wall of hard plastic anchored into the ground) to be the most cost-effective and environmentally desirable. The estimated cost is $3,640,000, bringing the total cost for seawall maintenance and shore stabilization to $6,222,000.

- More expensive is a common current adaptation to climate variability in coastal zones, beach nourishment. Beach nourishment costs for projects in New York State as well as all coastal states on the East and Gulf coasts are given in NOAA (n.d.). Among projects in New York State in the 1990s are Coney Island (1995), with an estimated project cost of $9 million and a length of 18,340 feet; and Westhampton Beach in Suffolk County (1996), with an estimated cost of $30.7 million and a length of 12,000 ft. Beach nourishment provides a good example of how appropriate adaptations will vary with time. With increasing SLR, beach nourishment is likely to become less attractive, especially in areas with no retreat room for beaches. In addition, as sea level rises beach nourishment can be counterproductive if it encourages increased coastal construction

- An example of large-scale adaptation measures for the coastal zone is the set of surge barriers that have been suggested as a possible protective measure for parts of New York City. These would consist of barriers on the upper East River, the Arthur Kill, and the Narrows, or alternative a larger Gateway system. The hydrologic feasibility of such barriers is studied in Bowman et al. (2005). Preliminary estimates for the NY Harbor barriers given by the designers were $1.5 billion for the upper East River site, $1.1 billion for the Arthur Kill, $6.5 billion for the Narrows barrier, and $5.9 billion for the Gateway barrier system (American Society of Civil Engineers [ASCE], 2009). These options are described in Aerts et al. (2009). According to those authors, "These options are at present only conceptual, and would require very extensive study of feasibility, costs, and environmental and social impacts before being regarded as appropriate for implementation. New York City has high ground in all of the boroughs and could protect against some levels of surge with a combination of local measures (such as flood walls) and evaluation plans; and barriers would not protect against the substantial inland damages from wind and rain that often accompany hurricanes in the New York City region" (Aerts et al., 2009, p. 75). Thus, the barrier costs cannot be directly compared to insured losses of property, because they would only protect against a subset of the surge impacts that will be expected; further detailed study would be required for a full benefit-cost analysis. Moreover, there is no obvious barrier system for Long Island short of Dutch-style dikes protecting large stretches of the region.

Table 3.6. Adaptations to Climate Change/Current Variability, with Locations and Costs

Adaptation	Climate (current or future) and/or other variables	Location	Estimated Cost
Reconnecting a salt marsh	Adapt to development	LI Sound (CT shoreline)	Total cost $60,000 to $141,000 for 10 acres
Wetlands restoration	Sea level, storm surge	Jamaica Bay-Elders West	$10 million for 40 acres
Wetlands restoration	Sea level, storm surge	Soundview	$5 million for 4 acres
Sea wall repair	Sea level, storm surge	Roosevelt Island	$6,222,000
Beach nourishment	Sea level, storm surge	Coney Island (1995)	$9,000,000
Beach nourishment	Sea level, storm surge	Westhampton Beach (1996)	$30,700,000
Storm surge barriers	Sea level, storm surge	New York Harbor	$9.1 billion for 3-barrier system

In considering this set of adaptation examples, it becomes clear that the menu of adaptations for the coastal zone will vary over time and space. There are some adaptations that are reasonable in cost (evacuation planning, sea walls) that are likely to avoid some impact costs in the next few decades. There are other adaptations that are likely to become less appropriate later in the century as beaches and salt marshes are lost; and there may be large-scale infrastructure investment that would be appropriate later in the century and that need to be studied more intensively.

The Multihazard Mitigation Study (2005a) presented a full benefit-cost analysis of FEMA Hazard Mitigation grants, including one set of grants to raise streets and structures in Freeport, NY (pp. 63-64 and 107) to prevent flooding under existing conditions. The analysis for housing elevation is presented here (the street analysis is in the transportation chapter). The total costs were $2.36 million; the grants for raising private structures required local matching funds of 25 %; the match for raising private buildings was paid by the owners. The study examined a wide range of parameter values of benefits and costs, and concluded that the total Freeport benefit-cost ratio best estimate for this adaptation to coastal flooding was 5.7, with a range of 0.18-16.3 (Table 3.7). This provides some sense of what might be required in the future in coastal areas such as Freeport, which of course do not have underground transit lines as does the inner core of the NYMA.

Table 3.7. Costs, Benefits, benefit-cost ratios and ranges for HMGP grant activities in Freeport, NY.

Activity in Freeport, NY	**Total Costs (2002 $M)**	**FEMA Costs (2002 $M)**	**Best Estimate Benefits (2002 $M)**	**Best Estimate Benefit-Cost Ratio**	**BCR Range**
Building Elevation	$2.36	$1.77	$13.5	5.7	0.18-16.3

Source: adapted from: Multihazard Mitigation Council, 2005b, vol. 2

3.5 Summary and Knowledge Gaps

From the standpoint of improving the ability of planners to do economic analysis of the costs of impacts and adaptations in the ocean and coastal sector, there are many knowledge gaps to which resources can be directed. Some of these are similar to recommendations for the transportation sector.

- A comprehensive data set in GIS or CAD form of as-located elevations of coastal infrastructure
- Updating of FEMA and other flood maps for rising sea levels
- A new Department of Environmental Conservation (NYSDEC) study of the amounts of coastal wetland remaining in New York State
- Studies of marsh and beach retreat areas, and the development of a typology of such areas that indicates which are most likely to be protectable with available adaptations
- Evaluation of the relationship of insured property to total property values
- Undertaking of a series of comprehensive benefit-cost analysis of potential adaptations to aid in long term planning.

- Review of local and state planning and environmental regulations to insure that, to the extent possible, they are compatible with and act as drivers of coastal adaptation measures.

Technical Notes – Ocean Coastal Zones Sector

Method for extrapolation of insured damages:

1. To consider plausible future damage figures from coastal flooding, the average insured damages figure for New York State is a starting point. This figure was $440 million (2010 $) for the period from 1990 to 2009. Insured damages in the example include losses to property from coastal flooding, and in some cases, business interruption losses.
2. To estimate 2010 damages, the average was taken at the midpoint (1999) and increased by 2.4% annually, to $545 million.
3. Of insured damages in New York State, about 46% are in coastal counties (2004 figures). Of those damages, 61% are from winter storms and hurricanes, and perhaps one quarter of this is from flooding (the rest is from winds); the damages from flooding and winds are not calculated separately in the data.
4. Applying these factors to the starting point of $545 million in insured damages, the figure applicable to coastal flooding is $38 million.
5. This figure will grow (at 2.4%) as shown in Table 3.2. These are damages without the impact of sea level rise and the consequent increase in flooding at each level.
6. Floods (because of SLR) become about 10% more frequent in the 2020s, 40% more frequent in the 2050s, and 70% more frequent in the 2080s (NPCC 2010) for the low estimate of SLR, and become about 30% more frequent in the 2020s, 70% more frequent in the 2050s, and 90% more frequent in the 2080s (NPCC 2010) for the low estimate of SLR.
7. These factors were applied to the damages in order to yield estimates of the additional flooding damages brought about by climate change. These figures, which are approximations because of topographical considerations for the specified years are given in the table. From these figure for 3 separate years, it will become apparent that total increased damages from coastal flooding over the forecast year will be in the many billions of $US. This conclusion will hold even with sensitivity on the assumptions.
8. Estimated adaptation costs are based on examples in the text for building elevation, sea walls, emergency planning, beach nourishment, and wetlands management.
9. Reductions in impacts (benefits from adaptations) are estimated using the empirically determined 4:1 benefit to cost estimate (references in the ClimAID transportation chapter), which is appropriate for infrastructure-intensive sectors.
10. For Table 3.1, beach and natural area losses are increased by GDP growth (2.4%) annually. These losses and the losses from the insured sector have some overlap, so that the figures are not strictly additive.
11. The insurance industry, which compiles the insured value data cited here, has long been concerned with climate change, as evidenced by the participation of one large company, Swiss Re, in the Economics of Climate Change Working Group (2009).

4 Ecosystems

The ecosystems sector in New York State includes the plants, fish, wildlife, and resources of all natural and managed landscapes in the state. Ecosystem services provided by New York's landscapes include preservation of freshwater quality, flood control, soil conservation and carbon sequestration, biodiversity support, and outdoor recreation (Wolfe and Comstock, forthcoming-a). Climate change is likely to have substantial impacts on the state's ecosystems, yet knowledge about both the precise nature of these impacts and options for adaptation is extremely limited. A further difficulty with economic cost estimates arises because ecosystems have intrinsic, non-market value associated with provision of habitat for many species, and preservation of wild places and heritage sites. Monitoring of the effects of climate change on ecosystem health, including threats from invasive species, and identification of viable adaptation options will be essential for protection of the state's ecosystems. Preservation of critical ecosystem services will also be an important step for minimizing some of the costly impacts of climate change in other sectors in New York State including water resources, agriculture, and public health.

PART I: KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR ECOSYSTEMS

Key Economic Risks and Vulnerabilities

Climate change will alter baseline environmental conditions in New York State, affecting both ecosystem composition and ecosystem functions. The most economically important components of the ecosystem sector that are at risk from various facets of climate change include impacts on tourism and recreation, forestry and timber, and riparian and wetland areas. While it is possible to estimate the costs associated with climate change impacts for some of the key, revenue-generating facets of the ecosystem sector, such as snow-related recreation, fishing, and timber and forestry production, the impacts of climate change on many other types of ecosystem services, particularly forest-related ecosystem services are presently unknown. Viable options for adaptation within the ecosystems sector and the costs associated with these options are only beginning to be explored.

Information on key economic risks associated with climate change in the ecosystems sector is summarized in the climate and economic sensitivity matrix presented in Table 4.1. Table 4.1 presents mid-century estimates of the impact costs for three illustrative components of the sector including skiing (currently valued at approximately $1 billion/year), snowmobiling (currently valued at approximately $500 million/year), timber (currently valued at $300 million/year), trout fishing (currently valued at $60.5 million/year). Table 4.1 also includes a rough estimate of the impacts of climate change on freshwater wetland ecosystems services (currently valued at $27.7 billion/year).

Table 4.1. Climate and Economic Sensitivity Matrix: Ecosystems Sector (Values in $2010 US.)

Element	Main Climate Variables					Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
	Temperature	Precipitation	Extreme Events: rainfall	Sea Level Rise	Atmospheric CO_2			
Outdoor recreation and tourism	●	●				+ Summer tourism with longer season – Winter ski tourism with reduced snowpack – Winter snowmobile tourism with reduced snowpack	$694-844M/yr (winter snowmobiling and skiing loss)	Costs: $54M/yr Benefits: $73M/yr
Freshwater Wetlands and riparian areas			●	●		– Sea level rise and extreme rainfall events threaten viability of coastal riparian areas – Inland wetlands threatened by drought and extreme rainfall events	$358 M/yr (estimated value of the loss of 5 % of ecosystem services)	Unknown
Recreational fishing	●					+ Warm water fishing with higher water temperatures – Cold water fishing with higher lake temperatures	$46 M/yr (trout fishing loss)	Costs: $2M/yr Benefits: $9M/yr
Timber industry	●	●			●	+ Longer growing season + Increase growth with higher levels of CO2 – Increased damage from pests and invasive species	+$15 M/yr (timber harvest gain)	Costs: $12M/yr Benefits: $45M/yr
Forest ecosystem services	●	●	●		●	+ Longer growing season + Increase growth with higher levels of CO2 – Increased damage from precipitation variability and extreme events – Loss of high alpine forests	Unknown	Unknown
Total estimated costs of key elements							$1083-1233M/year	Costs: $68M/yr Benefits: $127M/yr

Key for color-coding:

	Analyzed example
	From literature
	Qualitative information
	Unknown

Together, the components included in table 4.1 are estimated to account for roughly one half of the total value of the ecosystems sector in the state. Important values that are not included in the impact cost numbers include new revenue that may be associated with expansion of summer recreational opportunities and expansion of warm-water recreational fishing. Although precise estimates of adaptation costs are presently unavailable, these costs are provisionally estimated to be approximately 1 to 3 percent of the projected economic value of each sector by 2050, and are expected to increase thereafter. It is also important to recognize that some adaptations (e.g. snowmaking to preserve skiing), may not be feasible later in the century due to substantially altered baseline climatic conditions.

Illustrative Key Costs and Benefits

Although the costs associated with climate change for some of the major ecosystem service components of the sector are uncertain or unknown, it is nonetheless possible to develop estimates of the costs of climate change impacts for critical, revenue-generating facets of the ecosystems sector. In Table 4.2 below, detailed estimates of the costs of climate change impacts on the state's snowmobiling, trout fishing, and timber industries are presented. Estimation of climate change impact costs for all revenue-generating facets of the ecosystems sector was beyond the scope of this study, however the three components selected for detailed analysis are illustrative of a range of revenue-generating ecosystem services which may be affected by climate change. Because the feasibility and costs of a range of adaptation measures for these three facets of the ecosystem sector have not been fully assessed, all estimates for adaptation costs and benefits should be regarded as provisional.

Results

Results (see Table 4.2) suggest that the impacts of climate change are likely to be highly varied across these three facets of the ecosystems sector. Substantial negative impacts are projected for both trout fishing and snowmobiling, both of which may be largely eliminated in New York State by the 2080s as the result of climate change. By the 2080s, annual losses associated with reductions in snowmobiling are expected to range from over $600 million to more than one billion dollars. Annual losses associated with the elimination of trout fishing are estimated to be in the range of $150 million. By contrast, climate change is expected to have positive effects for the state's future timber harvests due to both longer growing seasons and increased levels of atmospheric CO_2. By the 2080s, gains in timber harvesting as the result of climate change are expected total more than $40 million per year.

Table 4.2. Illustrative key impacts and adaptations: Ecosystems Sector (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)	Annual incremental costs of climate change impacts, without adaptation ($M)	Annual costs of adaptation ($M) [6]	Annual benefits of adaptation ($M) [7]
Snowmobiling and reduced snowpack[1]	Baseline	$25[2]	-	-	-
	2020s	$29	$139-$140[3]	$11	$46
	2050s	$45	$344-$494[3]	$18	$73
	2080s	$71	$649-$1068[3]	$28	$113
Trout fishing and impacts of higher water temperatures[1]	Baseline	$3[2]	-	-	-
	2020s	$7	$7[4]	$1	$6
	2050s	$12	$46[4]	$2	$9
	2080s	$18	$162[4]	$3	$15
Timber industry and impacts of longer growing season[1]	Baseline	$3[2]	-	-	-
	2020s	$3	$ -3[5]	$7	$28
	2050s	$5	$ -15[5]	$12	$45
	2080s	$8	$ -45[5]	$18	$71
TOTAL[8]	Baseline	$31	-	-	-
	2020s	$39	$144	$19	$80
	2050s	$62	$375-$525	$32	$127
	2080s	$97	$760 - $1180	$49	$199

[1] *Value of sector is projected to increase between 1.0 and 2.0 percent per year in New York State. Average increases of 1.5 percent per year are shown in the table. Climate change impact and adaptation cost estimates in the table are estimated based on a growth rate of 1.5 percent.*

[2] *Baseline losses are assumed to be 5% per year for snowmobiling, 5% per year for trout fishing and 1% per year for timber harvesting.*

[3] *Based on Scott et al. (2008) estimates of reductions in snowmobile days for four New York snowmobile regions using low (B1) and high (A1fi) emissions scenarios.*

[4] *As the result of climate change impacts, trout fishing is expected to be eliminated in unstratified lakes by 2050 and in stratified lakes by 2080 (Wolfe and Comstock, forthcoming-a, trout fishing case study).*

[5] *Climate change is expected to have positive impact on timber harvests in New York State due to longer growing season and increased CO_2. Impacts are estimated for a range of values: .5 to 1.5 percent in 2020, 2 to 3 percent in 2050, and 4 to 6 percent in 2080. Midpoint values are shown in the table.*

[6] *Estimates of the costs of climate change adaptation are assumed to be approximately 1 to 3 percent of the total economic value each sector. Midpoint values are shown in the table. It should be noted that these estimates are provisional. Further analysis of adaptation options, feasibility and costs is needed.*

[7] *Benefits of adaptations are assumed to total four times the value of each dollar spent on adaptation. These estimates are preliminary and provisional. Further analysis of adaptation options, feasibility and costs is needed.*

[8] *Totals are based on mid-point values, expect in cases where multiple climate change scenarios are available.*

Overall, development of options for adaptation to climate change in the ecosystem sector is still in a preliminary stage. We assume for illustrative purposes that adaptation costs will range from approximately 1 to 3 percent of annual revenue in the three sectors. By the 2080s, midpoint estimates of annual adaptation costs for all three components are approximately $49 million per year.

PART II: BACKGROUND

4.1 Ecosystems in New York State

The state's terrestrial ecosystems include forests, meadows, grasslands and wetlands. Coastal ecosystems include coastal wetlands, beaches and dune areas, and Hudson River tidal processes. Sixty one percent of New York's land area, or 18.5 million acres, is covered by forest canopy, 40 percent of which (7.4 million acres) is occupied by Northern hardwoods. Tree species with important functional roles include spruce and fir, which are key components of the unique and highly cherished high-elevation forests of the Adirondacks, and hemlocks, which provide shade to stream banks (essential for coldwater fish species) and habitat for many other species. New York's inland aquatic ecosystems depend upon the state's rich abundance of water resources including seventy thousand miles of streams and rivers and 4,000 lakes and ponds (Wolfe and Comstock, forthcoming-a; NYSDEC 2010a).

New York's terrestrial and aquatic ecosystems provide habitat for 165 freshwater fish species, 32 amphibians, 39 reptiles, 450 birds, including many important migratory bird species, 70 species of mammals, and a variety of insects and other invertebrates. Three mammal species - the New England cottontail (*Sylvilagus transitionalis*), the small-footed bat (*Myotis leibii*) and the harbor porpoise (*Phocoena phocoena*) - are state species of concern and one species, the Indiana bat (*Myotis sodalis*) is federally endangered. The Hudson River Valley is globally significant for its diversity of turtles (Wolfe and Comstock, forthcoming-a).

The vast majority of New York's forests and other natural landscapes are privately owned (e.g., over 90 percent of the state's 15.8 million acres of potential timber land). The state also contains over 2.4 million acres of freshwater wetlands, 1.2 million of which are legally protected and administered by the DEC and 0.8 million by the Adirondack Park Agency (NYSDEC 2010b). The Army Corps of Engineers also has jurisdiction over some wetlands in New York State. The economic value of goods and services provided by New York's ecosystems includes recreational and tourism value, the value of commodities such as timber and maple system, and the value of wide array of ecosystem functions including such as: carbon sequestration; water storage and water quality maintenance; flood control; soil erosion prevention; nutrient cycling and storage; species habitat and biodiversity; migration corridors for birds and other wildlife. These functions have substantial economic value, but quantifying them is complex. Also difficult to quantify are the "existence" or "non-use" values, associated with concepts such as preservation of cultural heritage, resources for future generations, charismatic species, and "wild" places (Wolfe and Comstock, forthcoming-a).

A useful illustration of the economic value of ecosystems services in New York is the example of New York City's decision in 1997 to invest in the protection of Catskills watersheds in order to avoid the cost of constructing and operating a large-scale water filtration system for the city's upstate water supplies. The new, larger filtration system was estimated to cost between $2 billion to $6 billion (National Research Council 2004) with operation costs estimated to be $300 million annually for a total estimate of $6 to $8 billion (Chichilnisky and Heal, 1998). By contrast the cost estimates of the city's watershed protection efforts within the Catskills are in the range of $1 billion to $1.5 billion over 10 years, therefore preservation of the ecosystem services provided by the Catskills watersheds has saved the city between $4.5 and $7 billion in avoided costs.

A recent study of the value of ecosystems services in New Jersey also provides some useful estimates for the per acre value of a range of other ecosystem services. The New Jersey study identified a broad spectrum of services that are provided by the state's beaches, wetlands, forests, grasslands, rivers, estuaries, including regulation of climate and atmospheric gas, disturbance prevention (e.g., flood and storm surge protection), freshwater regulation and supply, waste assimilation, nutrient regulation, species habitat, soil retention and formation, recreation, aesthetic value, pollination. The study provided estimates of the average per acre and total values of these services within the state based on value transfer methods, hedonic analysis and spatial modeling (Costanza et al. 2006). The study found that some of the highest per acre value ecosystems are provided by beaches ($42,147/acre-year), followed by estuaries ($11,653/acre-year), freshwater wetlands ($11,568/acre-year), saltwater wetlands ($6,131/acre-year), and forests ($1,476/acre-year). In total, the report estimates that New Jersey's ecosystem services provide economic value for the state of between $11.4 and $19.4 billion per year (Costanza et al. 2006, p. 18). Given New York's vastly greater land area (New Jersey's land area is 5.5 million acres compared to more than 30 million acres in New York), the value of ecosystem services in New York would be expected to be substantially larger. New York's 18.5 million acres of forest canopy alone would have an estimated value of more than $27 billion, based on the estimate of $1,476 annual value per acre used in the New Jersey study.

While ecosystem service values can be difficult to quantify, values associated with human recreational usage of ecosystems are somewhat more straightforward. Outdoor recreation and tourism directly contributes over $4.5 billion to the state's economy. Over 4.6 million state residents and nonresidents fish, hunt, or wildlife watch in New York State (USFWS 2006), spending $3.5 billion, including equipment, trip-related expenditures, licenses, contributions, land ownership and leasing, and other items. The 2007 New York State Freshwater Angler Survey indicated over 7 million visitor-days fishing for warm water game fish (predominantly smallmouth & largemouth bass, walleye and yellow perch), and nearly 6 million days in pursuit of coldwater gamefish (predominantly brook, brown, or rainbow trout) (NYSDEC 2009). Total annual fishing expenditure at the fishing site was $331 million in 2007 (Connelly and Brown 2009a, p. 77). Trout fishing (brook, brown, and rainbow) accounted for 18.3 percent of estimated angler days in the state in 2007 (estimated based on Connelly and Brown, 2009a, p. 16), and the annual value of trout fishing for the state's economy is estimated to be $60.5 million/year.

The state's ski areas host an average of 4 million visitors each year, contributing $1 billion to the state's economy and employing 10,000 people (Scott et al. 2008). New York is also part of a six-state network of snowmobile trails that totals 40,500 miles and contributes $3 billion a year to the Northeast regional economy. Assuming New York accounts for one-sixth of this economic impact, it is estimated that snowmobiling currently brings $500 million to the state's economy overall. The local economies of the Adirondacks, Catskills, Chautauqua-Allegheny, and the Finger Lakes areas are especially dependent on outdoor tourism and recreation, including skiing, hiking, boating and fishing. Table 4.3 provides 2008 data on the economic impact of tourism in these regions. In total, visiting spending in these five regions surpassed $5.3 billion and generated more than $353 million in state tax revenue and $336 million in local tax revenue.

Table 4.3. Economic Impact of Tourism in Selected Regions of New York State.

Region	Visitor Spending ($ millions)	Total employment in tourism and recreation	Share of regional employment in tourism and recreation	State Tax Revenue associated with tourism ($ millions)	State Tax Revenue associated with tourism ($ millions)
Adirondacks	$1,128	20,015	17%	$78	$74
Catskills	$988	17,411	15%	$64	$64
Chautauqua-Allegheny	$500	11,101	11%	$33	$32
Finger Lakes	$2,606	57,083	6%	$180	$166
Total	$5,223	105,610		$354	$337

Source: Tourism Economics 2009. Total figures calculated by authors.

Timber and non-timber forest products such as maple syrup are also significant for the state's economy. In 2005, the estimated value of timber harvested in the state exceeded $300 million (North East Foresters Association [NEFA], 2007). The manufactured conversion of these raw timber components into wood products such as commercial grade lumber, paper and finished wood products adds considerably to the value of this industry to the state. The total forest-based manufacturing value of shipments in 2005 was $6.9 billion (NEFA 2007). Each 1000 acres of forestland in New York is estimated to support 3 forest-based manufacturing, forestry and logging jobs. In 2007, the state's wood products industry employed 9,991 people with an annual payroll of $331 million (United States Census Bureau 2010a). The state's paper manufacturing industries employed 16,868 people with an annual payroll of $748 million (United States Census Bureau 2010a). These industries are particularly important to the regional economies of areas like the Adirondacks, where wood- and paper-product companies employ about 10,000 local residents (Jenkins 2008). In 2007, New York produced 224,000 gallons of maple syrup (2nd in the US, after Vermont) at a value of $7.5 million (USDA NYSS 2009). The Northeast State Foresters Association, using US Forest Service statistics for 2005, found that forest-based recreation and tourism provided employment for 57,202 people and generated a payroll of $300 million in the region (NEFA 2007).

4.2 Key Climate Change Sensitivities

Climate change is likely to have substantial effects of the composition and function of New York State's ecosystems. While this report emphasizes climate change related impacts, it is important to recognize that effects of climate change cannot be viewed in isolation, as other stressors such as urbanization and land use change, acid rain, and invasive species are also affecting ecosystems and will affect vulnerability and capacity to adapt to climate change. Key climate related ecosystem sensitivities are summarized in Table 4.4:

Table 4.4. Climate change sensitivities: Ecosystems Sector (See Wolfe and Comstock, forthcoming-a, for further details).

Higher atmospheric carbon dioxide can increase growth of many plant species. Higher levels of CO_2 are likely to alter species composition in some New York State ecosystems, favoring some species over others. Fast-growing invasive plants and aggressive weed species tend benefit most from higher levels of CO_2.
Warmer summers and longer growing seasons will affect species composition, benefitting some plant and animals species, but harming others. Insects and insect disease vectors will benefit in multiple ways, such as higher food quality of stressed plants, more generations per season and increased over-winter survival. In aquatic systems, warmer waters will tend to be more productive, but are also more prone to nuisance algal blooms and other forms of eutrophication.
Higher temperatures and increased frequency of summer heat stress affects many plant and animal species, constraining their habitable range and influencing species interactions. Temperature increases will drive changes in species composition and ecosystem structure, most notably leading to eventual loss or severe degradation of high elevation spruce-fir, krumholz, and alpine bog and tundra habitats.
Warmer, more variable winters, with less snow cover will have substantial effects on species composition. The habitable ranges of many plant, animal, and insect species that are currently located south of New York may shift north.
Increasing frequency of high rainfall events and associated short-term flooding is currently an issue and is projected to continue. This leads to increased run off from agricultural and urban landscapes into waterways with possible pollution or eutrophication effects, erosion and damage to riparian zones, flood damage to plants, and disturbance to aquatic ecosystems. Extreme events from climate change can cause radical to ecosystem composition. Ecosystems that are already under stress (e.g. forested areas that have been subject to drought or insect invasion) are less resilient to extreme events.
Summer soil water deficits are projected to become more common by mid- to late-century, and the impacts on ecosystems will include reduced primary productivity, and reduced food and water availability for terrestrial animals. Summer water deficits could lead to a reduction of total wetland area, reduced hydroperiods of shallow wetlands, conversion of some headwater streams from constant to seasonal flow, reduced summer flow rates in larger rivers and streams, and a drop in the level of many lakes.

4.3 Impact Costs

Existing efforts to assess the impact costs of climate change for ecosystems are quite limited and typically focus on impacts associated with specific facets of ecosystem services such as snow-dependent tourism in Northeast U.S. (Scott et al. 2008). Broad-based global assessments of ecosystems costs of climate change are also limited (e.g., Tol 2002; Nordhaus and Boyer 2000). More typically, ecosystem studies include qualitative discussion of potential costs associated with climate change (e.g. Parry et al. 2007). For New York State, it is possible to identify a number of areas where impact costs are likely to be incurred. It is important to note, however, that the climate change impacts to New York State's ecosystems are likely to be substantial, regardless of our ability to assign a dollar amount to each impact.

Winter and summer recreation. Under climate change, higher temperatures, reduced snowfall and more variable winter temperatures will have a detrimental effect on the state's $1.5 billion snow-dependent recreational industries including skiing and snowmobiling. While substantial losses in the ski industry are unlikely until much later in the century due to the snowmaking capacities of many resort areas, conditions will become less favorable for skiing within the next several decades. Snowmobiling – which is more dependent on natural snow – is likely to decline substantially in western, northeastern, and southeastern New York within the next several decades (Scott et al. 2008, p. 586). By the mid-21st century, annual economic losses for snowmobiling alone could total $420 million/year (see Tables 4.1 and 4.2). By mid-century expected annual reductions of ski-season length for three major ski regions in New York (Western, Northeastern and Southeastern) are expected to be in the range of 12 to 28 percent. The lower estimates are based on the B1 (lower) emissions scenario while the higher estimates are based on the A1Fi (higher) emissions scenario. Excluding the costs associated with snowmaking, the direct costs associated with these reductions in the ski season range from approximately $200 million per year to more than $500 million per year. A midpoint loss estimate of $350 million is used in Table 4.1 above. Addition of snowmaking costs would substantially increase the total cost estimates.

Summer recreational opportunities such as hiking, swimming and surface water sports are likely to expand with earlier onset of spring weather and higher average summer temperatures. Outdoor tourism and recreation is especially important for rural counties in the Adirondacks, Catskills, and Finger Lakes regions. It is possible that a large share of winter recreation losses could be offset by increases in summer recreational activities.

Recreational fishing. Rising temperatures are likely to have a deleterious effect on cold-water recreational fish species, including brook and lake trout, which currently add more than $60 million per year to the state's economy from on-site fishing-related expenditures (see Table 4.2). Although warm-water species such as bass are likely to benefit from climate change, cold-water recreational species are more desirable for many angler tourists from other regions where these species are less plentiful. Within the Adirondacks, total fishing-related expenditures within the local region were estimated at approximately $74.5 million in 2007, and expenditures by anglers from other regions of New York and out-of-state represented more than 85 percent of this total (Wolfe and Comstock, forthcoming-a; Connelly 2010; Connelly and Brown 2009a, 2009b). Loss of revenue associated with those anglers from other regions or states who are specifically coming for trout and other cold-water species would represent a significant economic blow to the area's tourism-related industries such as hotels, gas stations, and restaurants. For the state as whole, annual trout-fishing losses are estimated to be more than $40 million/year by mid-century (see Tables 4.1 and 4.2).

Timber Industry. Climate change presents both opportunities and challenges for the state's timber industry. Climate change is expected to enhance hardwood production in the state as the result of higher levels of atmospheric CO_2 and a longer growing season. By mid-century the estimated additional value to the timber industry is estimated to be $14 million/year (see Tables 4.1 and 4.2). However, it is also possible that the state's forested areas could become less ecologically diverse as climate changes. Moreover, the transition to a warmer climate may create stresses for some tree species making them less able to withstand normal climatic shocks, leading to dramatic shifts in species composition following extreme events. The timber industry will also face additional costs to manage greater populations of deer and other invasive species that threaten tree survival and timber quality.

Maple syrup production. Maple syrup production may increase under climate change. However, syrup production in lower cost regions such as Quebec may also increase, potentially affecting the competitiveness of the industry.

Heritage value of spruce forests. Spruce forests in New York State have aesthetic and heritage value for state residents, and are also an attraction for summer recreational tourists. These forest ecosystems are not expected to survive under climate change.

Impacts on Riparian Areas. Water quality and flood protection are key ecosystem services provided by riparian areas. These areas also provide critical avenues for species dispersal. Within New York State, the ecosystem services associated with freshwater wetlands are currently valued at more than $27 billion. Although the direct impacts of climate change on wetland and riparian areas are unknown, these areas are already under considerable stress due to land use changes, particularly urban development. New development in and around riparian areas often undermines the water quality and flood protection services associated with these areas.

Costs of invasive species. Invasive plant and animal species have profound ecological and economic impacts and climate change is expected to exacerbate invasive species threats. Within New York State, invasive species pose serious economic threats to agriculture, forestry, maple sugar production, and recreation (Wolfe and Comstock, forthcoming-a). For the U.S. as a whole, invasive species have been estimated to cost the U.S. $120 billion per year in damage and control expenditures (Pimentel et al. 2005). A single species, the emerald ash borer (***Agrilus planipennis*** Fairmaire), which is now established in 13 states including New York, is estimated to cost $10.7 billion from urban tree mortality alone over the next 10 years (Kovacs et al. 2010). Within New York State, Hemlock is currently threatened by infestations of the insect pest, hemlock wooly adelgid (Paradis et al 2008), and grassland ecosystems are also threatened by a number of fast-growing invasive species.

4.4 Adaptation Costs

Assessments of the adaptation costs of climate change for ecosystems are also limited and tend to be focused on specific ecosystem subsectors, such as forestry, within particular regions or countries. With the exception of the United Nations Framework Convention on Climate Change (UNFCCC 2007), recent comprehensive studies of adaptation costs such as that of Stern (2007) do not explicitly include ecosystem adaptation cost estimates. Furthermore, many proposed options for specific adaptations are based largely on ecological theory and have not been tested for their practical effectiveness (Berry 2009). The UNFCCC adaptation costs estimates, which are based primarily on enhancement of the global terrestrial protected areas network, indicate that additional annual expenditures of $12 to $22 billion are needed. Because these estimates do not include marine protected areas or adaptation for non-protected landscapes, they are likely to underestimate the full costs of ecosystem adaptation (Berry 2009).

Despite the lack of generally knowledge about the true costs associated with ecosystem adaptation and the effectiveness of ecosystems adaptation measures, there is nonetheless a consensus within the literature that human intervention will be needed in order to enhance ecosystem adaptation and protect ecosystem integrity and ecosystem services (Berry 2009).

Monitoring and responding to climate change threats to ecosystem functions. A key adaptation entails institutionalizing a comprehensive ecosystems database and monitoring effort. This could potentially entail a state government position with an agency such as the Department of Environmental Conservation. Monitoring and development of indicators for species movement are critical for the management of climate change adaptation by species. In many cases, the need to monitor invasive species and to react quickly, perhaps even with chemical intervention. Costs associated with responding to insect pests can be substantial. For example, since 1996, the annual cost of controlling Asian longhorned beetles in New York City and Long Island has ranged between $13 million and $40 million (New York Invasive Species Clearinghouse 2010).

The costs associated with monitoring efforts for invasive species would likely be similar to the costs associated with the Integrated Pest Management (IPM) program for agriculture. That program, budgeted at $1 million/year entails monitoring of insect pests in New York State and development of responses that can be implemented by farmers while minimizing use of chemical insecticides (NYSIPM 2010). An effort that is similar in scope to the IPM program would monitor indicators of climate change and identify threats to ecosystem services associated with climate change. In particular, the monitoring program would need to: identify good indicators of ecosystem function; monitor these indicators; monitor native species and species interaction – e.g. presences of correct food at correct time of year for migrating birds; monitor invasive species, with a focus on tracking devastating species that may be entering New York State. The annual cost of such a program would be on at least on par with the $1 million/year IPM program budget. The broader goal of such a monitoring program would be to help maintain ecosystem functions under climate change, including management of transitions to new climate conditions.

Adapting outdoor tourism to new climatic conditions. While outdoor tourism will likely continue to be a robust sector in New York State, adaptation to climate change will require new investment on the part of tourism operators in order to maintain profitability and take advantage of opportunities associated with a warmer climate. Within the skiing industry, for example, potential strategies may include expansion of snowmaking capacity and addition of summer season offerings at ski resorts such as hiking and mountain biking or development of new ski resorts at higher altitude and in more northern areas. Managers of state parks and forests will also need to prepare for changes in patterns or seasonality of tourism and demand for recreational services, such as greater use of campgrounds during the fall and spring seasons.

Protection of Forests, Riparian and Wetland Areas. Intact forests, particularly in riparian areas, provide critical ecosystems services including flood control and maintenance of water quality. Forest related ecosystems services are also critical for meeting the state's climate change mitigation goals. Planned mitigation programs that entail incentives for private landowners to leave forests intact could potentially dovetail with the goals of adaptation. Protection of natural corridors in forested riparian areas may provide other ecosystem benefits such as facilitating adaptation of species to climate change. Protection and/or restoration of wetlands in both inland and coastal areas is also critical for flood control, maintenance of water quality, and preservation of habitat for many species.

The benefits associated with protection of wetlands are illustrated in Table 4.5, based on the estimates of Costanza et al. (2006) on the per acre value of wetlands. Once a wetland has been lost or destroyed, the costs of restoration can be very high on a per acre basis. Table 4.5 provides per acre cost estimates for both coastal and inland restoration in New York State. The coastal costs per acre are based on the costs of restoration for two areas on Long Island, while the inland costs are based on costs associated with restoration of wetlands around the Peconic River. For the state as a whole, freshwater wetlands provide ecosystem service benefits valued at more than $27 billion per year. Costs of freshwater restoration of wetlands can range from $3,500 to $80,000 per acre and may entail activities ranging from simple preparation of soils and planting new vegetation to replacement of soils, grading, and planting trees (Brookhaven National Laboratory [BLN] 2001).

Table 4.5. Benefit Cost Analysis of Potential Climate Change Adaptation: Inland Wetlands

Type of Wetland	Total acres	Value of Ecosystem Services per acre	Total value of ecosystem services	Cost of Restoration (per acre)	Costs of a 10 acre restoration project	Ecosystem Service Benefits of a 10 acre project
Freshwater (New York State)	2,400,000	$11,568	$27.7 billion (NY State)	$3,500 (low) $80,000 (high)	$30,000 (low) $800,000 (high)	$115,658

Sources: NYCDEC 2010; Costanza 2006; BNL 2001; United States Army Corps of Engineers 2010; Authors' calculations of total costs.

4.5 Summary and Knowledge Gaps

While it is possible to estimate economic impacts associated with revenue-generating activities such as winter tourism, timber, and recreational fishing, there is limited knowledge about the broader ecosystem impacts of climate change and options for adaptation. For example, it is likely forests will still continue to dominate many portions of interior New York State under climate change, yet composition of the forests will be different. Such changes in forest composition will have uncertain effects on ecosystems services associated with forests including timber quality and quantity, water quality, and flood control, all of which are critical for adaptation to climate change.

Within New York State, a number of activities may help to facilitate effective adaptation to climate change including monitoring of threats to ecosystem function, adjustment of tourism and recreational planning and opportunities to meet changing seasonal demands, and protection of areas that provide critical ecosystem services associated with species habitat, water quality, and flood protection.

In terms of research needs and gaps, some key areas include:

- A comprehensive assessment of the value of ecosystem services in New York State;
- Monitoring of ecosystem health and invasive species;
- More in-depth analysis of the direct and indirect economic effects of climate change on key ecosystem services in the state and on the state's ecosystem-dependent, outdoor recreation sectors.
- Development and testing of tools for management of ecosystems, including identification of ways to strengthen the adaptive capacity of the state's ecosystems.

- Development and testing of specific, targeting adaptation strategies, particularly for protection or preservation of critical ecosystem services.

- Development and testing of provisional, "best available data" interval estimates of cost associated with other ecosystem losses. Exploration and development of different and novel methodologies for doing so.

Technical Notes – Ecosystems Sector

1. The current annual value of the snowmobiling in New York State is estimated to be $500 million, assuming New York State accounts for one-sixth of the revenue associated with the $3 billion, six-state Northeast snowmobile network (Wolfe and Comstock, forthcoming-a). The current value of trout fishing in the state is estimated to be $60.5 million/year (based on Connelly and Brown 2009a). The current value of the timber industry is estimated to be $300 billion (NEFA 2007). Each of these facets of the ecosystem sector is projected to grow by between 1.0% and 2.0% per year. A midpoint value of 1.5% is used in the table. These lower growth rates are used in the sector because of natural limitations on increases in both resource stocks and land availability.

2. Baseline climate-related revenue losses are assumed to be 5% per year for snowmobiling, 5% per year for trout fishing, and 1% per year for timber harvesting.

3. As the result of climate change impacts, trout fishing is expected to be eliminated in unstratified lakes by 2050 and in stratified lakes by 2080 (see Wolfe and Comstock, forthcoming-a, Trout fishing case study). Trout fishing revenues are estimated to decline by 20 percent by 2020, 50 percent by 2050, and 100 percent by 2080. Although it likely that other recreational fishing species may replace trout in the future, estimates of new revenue associated with such species are not included in this analysis. It also important to recognize that warm water species such as bass are more ubiquitous throughout the Northeast and are therefore less attractive to tourists coming from other regions.

4. The snowmobiling and skiing impacts are based on Scott et al.'s (2008) estimates of reductions in snowmobile and skiing days in New York using low (B1) and high (A1fi) emissions scenarios.

5. Climate change is expected to have positive impact on timber harvests in New York State due to longer growing season and increased CO_2. Positive impacts are estimated to be 1% in 2020, 2.5% in 2050, and 5% in 2080.

6. Without adaptation, both snowmobiling and trout fishing are likely to be largely eliminated in the state by the 2080s, while timber production is likely to expand. Estimates of the costs of climate change adaptation are assumed to be approximately 1 to 3% of the total economic value of each of the sectors. These estimates are preliminary and provisional. Further analysis of adaptation options, feasibility and costs is needed.

7. Benefits of adaptations are assumed to total four times the value of each dollar spent on adaptation. These estimates are preliminary and provisional. Further analysis of adaptation options, feasibility and costs is needed.

5 Agriculture

Climate change presents economic challenges and opportunities for agriculture in New York State. While New York can be expected to maintain and potentially expand its highly productive agricultural sector as climate change progresses, the crops grown are likely to change as the climate becomes more suitable for warmer weather products. The structure of the industry may also change substantially over the next several decades, with continued trends toward consolidation. These shifts will be due in part to pressures associated with climate change, but also to other social and economic factors. For example, there is already a trend toward consolidation, especially in the dairy sector due to reductions in demand and rising costs.

Although the analysis presented in this report emphasizes aggregate costs and benefits associated with climate change impacts and adaptation in the agriculture sector, it is important to recognize that smaller farms typically have less capital to invest in on-farm adaptation strategies (such as stress-tolerant plant varieties or increased chemical and water inputs) and less ability to take advantage of cost-related scale economies associated with such measures. Many of the state's smaller farmers may also lack the resources or information needed to make strategic adaptations (such as increased irrigation or cooling capacity on dairy farms) that will be required to remain profitable (see Leichenko et al., forthcoming; and Wolfe and Comstock, forthcoming-b). Ensuring that both small and large farms are able to take advantages of the opportunities associated with climate change will be an important challenge for New York State.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR AGRICULTURE

Key Economic Risks and Vulnerabilities

Climate change may cause production yield and quality losses due to increased frequency of summer drought, increased frequency of high rainfall events, higher summer temperatures, inadequate winter chill period, increased risk of freeze due to variable winters, and increased insect, disease, and weed pressures. (Wolfe and Comstock, forthcoming-b). At the same, a warmer climate and longer growing season may present new opportunities for expansion of agricultural production and introduction of new crop varieties that are currently more suited to production further south. Table 5.1 identifies risks and opportunities associated with climate change for the three major economic components of the state's $4.5 billion dollar agricultural sector. These components include the dairy and livestock production, valued at approximately $2.4 billion, fruits, vegetables and nursery crops valued at approximately $807 million, and field crops (most of which are used as feed for the dairy and livestock sector) valued at approximately $1.1 billion (United States Department of Agriculture National Agricultural Statistics Service [USDA NASS] 2009).

Table 5.1. Climate and Economic Sensitivity Matrix: Agriculture Sector (Values in $2010 US.)

Category	Main Climate Variables					Economic risks and opportunities – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
	Temperature	Precipitation	Extreme Events: rainfall	Sea Level Rise	Atmospheric CO_2			
Dairy and livestock	●			●		– Increased stress to livestock – Reduced milk production due to heat	$110M/yr (cost heat stress on dairy production)	Costs: $5M/yr (cooling dairy barns) Benefits: $79M/yr
Field Crops	●	●	●		●	+ Longer growing season + Increase growth with higher levels of CO2 – Increased weed and pest pressures – Higher risk of crop damage from drought	$20-102M/yr (cost extreme events and drought)	Costs: $42M/yr (pesticides, weed control, cropping changes) Benefits: $153M/yr
Perennial fruit crops, vegetables, nursery crops	●	●	●	●	●	+ Longer growing season + New crops and new varieties possible with warmer climate – Increased weed and pest pressures – Higher risk of crop damage from drought	$10-77M/yr (cost of extreme events and drought	Costs: $31M/yr (irrigation, pesticides, weed control, changes in crops varieties) Benefits: $115M/yr
Total estimated costs of key elements							$ 140-289M	Costs: $78M/yr Benefits: $347M/yr

Key for color-coding:

(dark blue)	**Analyzed example**
(medium blue)	**From literature**
(light blue)	**Qualitative information**
(white)	**Unknown**

Illustrative Key Costs and Benefits

As described in Table 5.1, the impacts of climate change on the state's agricultural sector are likely to be mixed. While higher temperatures and increased pest pressures will impose strains on dairy and crop production, a longer growing season with more frost free days is likely to have a beneficial effect for many crops, particularly if irrigation capacity is expanded. Table 5.2 presents rough estimates of the costs associated with climate change for the three main facets of the state's agricultural sector. Baseline climate impacts for each facet are based on either empirical documentation of historical losses or extrapolation of losses associated with past events. The costs of impacts of climate change entail estimation of the incremental increase in losses as the result of climate change, beyond the baseline estimates. For dairy production, these loss estimates are based on modeled scenarios of the impacts of climate change on milk production (see Wolfe and Comstock, forthcoming-b, Dairy case study). Estimates of the costs and benefits of adaptation are based on modeling results for the dairy sector (see Wolfe and Comstock, forthcoming-b, Dairy case study), and research suggesting that, with adaptation, most of the impacts of climate change could be substantially reduced or eliminated for agriculture within the Northeast U.S. (see Cline 2007).

For the other components of the sector, the climate change loss estimates are based on the assumption that, without adaptation, average climate change losses for agriculture will increase as the climate changes. Estimated losses in the range of 1% to 5% in 2020 and 2050, and 5% to 10% 2080, respectively, are used as illustrative estimates of the potential magnitude of the impacts of climate change. These estimates may be regarded as provisional pending a more detailed assessment of the effects of climate change on crop production under a range of climate scenarios, which was beyond the scope of this study.

Results

Results indicate that without adaptation, climate change will have substantial costs for the state's agricultural sector, potentially leading to losses of between $766 and $1047 million by the 2080s. However, with the implementation of adaptation strategies including cooling systems for dairy barns, expanded irrigation of crops, and expanded efforts at weed and pest control, future climate change impacts can be minimized. The gains with adaptation are expected to more than offset anticipated losses associated with climate change, leading to net gains in total crop production. By 2050, for example, crop production losses (i.e., losses of fruit, vegetables, nursery, and field crops) due to climate change are estimated to total as much as $179 million, while gains from adaptation measures are expected to total more than $268 million. Annual adaptation costs for the agricultural sector are expected to increase over time, totaling over $300 million/year by the 2080s.

Table 5.2. Illustrative Key Impacts and Adaptations: Agriculture Sector (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)	Annual incremental costs of climate change impacts, without adaptation ($M)	Annual costs of adaptation ($M)	Annual benefits of adaptation ($M)
Dairy Production and heat stress[1]	Baseline	$25[9]	-	-	-
	2020s	$29	$20[4]	$3[5]	$25[6]
	2050s	$45	$110[4]	$5[5]	$79[6]
	2080s	$71	$488[4]	$12[5]	$252[6]
Fruit, Vegetable and Nursery Crop Production and extreme events, drought, and higher temps[1]	Baseline	$13[10]	-	-	-
	2020s	$17	$9 - $49	$9[3]	$20[8]
	2050s	$27	$10 - $77[2]	$31[3]	$115[8]
	2080s	$43	$120 - $240[2]	$126[3]	$360[8]
Field Crop Production extreme events, drought, and higher temps [1]	Baseline	$33[10]	-	-	-
	2020s	$39	$13 - $55[2]	$14[3]	$26[8]
	2050s	$61	$20 - $102[2]	$42[3]	$153[8]
	2080s	$96	$158 - $319[2]	$167[3]	$479[8]
TOTAL	Baseline	$71	-	-	-
	2020s	$85	$42 - $124	$26	$71[7]
	2050s	$133	$140 - $289	$78	$347[7]
	2080s	$210	$766 - $1047	$305	$1091[7]

[1]*The baseline value of agricultural production is projected to increase between 1.0 and 2.0 % per year in New York State, based recent growth rates of GDP in this sector. Average values of 1.5 % per year are shown in the table.*

[2]*As the result of climate change impacts without adaptation, projected value is assumed to decline by between 1 and 5 percent in both 2020 and 2050, and 5 to 10% in 2080.*

[3]*Estimated costs of adaptation including additional irrigation, pest and weed control, and shifts in crop varieties. These estimated costs are provisionally estimated to range from .5 to 1.5% of value of baseline production in 2020, 1 to 3% percent of baseline production in 2050 and 4 to 6% percent in 2080. Average values are used in the table.*

[4] *Based on Wolfe and Comstock, forthcoming-b, estimates of costs of heat stress on milk production under the A2 climate change scenario and assuming changes in diet but no additional cooling capacity in dairy barns (see Wolfe and Comstock, forthcoming-b, Table 7.5)*

[5]*Estimated costs of adaptation based on costs of addition and operation of cooling systems for dairy barns, assuming costs per cow range from $10 to $110 (see Wolfe and Comstock, forthcoming-b, Dairy case study). Midpoint values are used in the table.*

[6]*With adaptation, the negative effects of heat stress on dairy production are estimated to be reduced by 50%.*

[7]*With adaptation, the total net effect of climate change on New York agriculture is expected to be positive with gains in crop production offsetting losses in dairy production.*

[8]*With adaptation, the net effect of climate change on crop production is expected to be positive due to both longer growing season and on-farm adaptations (e.g. irrigation, changing crop varieties, pest control). Gains of 1% in 2020, 2.5% in 2050, 5.0% in 2080, are projected based on Cline's (2007) estimates of 5% gain by 2080 without assuming CO_2 fertilization; values for 2020 and 2050 were extrapolated.*

[9] *Estimated current annual heat-related losses in dairy and livestock sector (see Wolfe and Comstock, forthcoming-b).*

[10]*Current annual climate-related losses for fruit, vegetables and nursery products and field crops are assumed to range from approximately 1.0 to 2.5 percent/year of the total value.*

PART II. BACKGROUND

5.1 Agriculture in New York State

New York State's agricultural sector contributes approximately $4.5 billion to the state's economy (USDA 2009). Table 5.3 summarizes some of the most recent (2007) New York agriculture statistics (www.nass.usda.gov/ny). Some of the largest commodities in terms of value include dairy ($2.4 billion), hay ($322 million), grain corn ($300 million), silage corn ($262 million), apples ($286 million), floriculture ($199 million), and cabbage ($100 million). New York is the dominant agricultural state in the Northeast, and typically ranks within the top five in the U.S. for production of apples, grapes, fresh market sweet corn, snap beans, cabbage, milk, cottage cheese, and several other commodities (see Table 5.4) (Wolfe and Comstock, forthcoming-b).

Table 5.3. 2007 NY Agriculture Value

Commodity	2007 Value (thousands)	2007 Harvested Acres (thousands)
Dairy and Livestock	2,727,299	N/A
Total Fruit Crops	368,267	84.25
Total Vegetable Crops	422,000	109.1
Total Field Crops	1,070,873	2769.5
Total Floriculture, Nursery, Greenhouse	357,661	
Total Livestock & Crops	4,454,294	

Source: USDA Nat Ag Stat Service: www.nass.usda.gov/ny
From Wolfe and Comstock, forthcoming-b, p. 36-37.

The agriculture sector plays a particularly important role in many of the state's rural regions. Although dairy farms occur throughout the state, they are the dominant component of the agricultural economy of many counties in the northern, central, and southern regions (Figure 5.1). In some of these more rural regions, a large fraction of the total economy is affected by the fate of the dairy sector. Many dairy farms also produce hay, corn (for grain and silage), and maintain some pasture land to support their own livestock, and for sale of hay. A large fraction of the state's high-value fruit and vegetable crops are grown in western New York, where cash receipts for these crops are highest. Long Island and the Hudson Valley region are also important fruit and vegetable crop areas (see Wolfe and Comstock, forthcoming-b). Small farms throughout the state are also vital to the economy of many rural areas, and fill an important market niche for fresh, high quality, affordable local produce (Wolfe and Comstock, forthcoming-b). About half of New York's 34,000 farms have sales below $10,000 (www.nass.usda.gov/ny), while 18 percent have sales exceeding $100,000. (Table 5.5).

Table 5.4. 2007 NY Agricultural Commodities: Significant Crops in Total Value for NY State and/or Crops with Top 5 National Rank

Product	2007 Total value (thousands)	NY State Rank	National Rank
Dairy products	2,377,987	1	1 (cottage cheese) 3 (milk)
Cattle, hogs, sheep	118,742		2 (calves) 6 (lambs & sheep)
Apples (total)	286,000	4	2
Grapes (total)	49,222		3
Tart cherries	4,369		4
Pears	5,120		4
Cabbage (fresh)	101,190		2
Sweet corn (fresh)	72,600		4
Snap bean (fresh)	49,749		4
Pumpkins (fresh)	22,694		4
Onions (fresh)	94,182		5
Potatoes (TOTAL)	64,372		11
Grain corn	300,355	3	22
Silage corn	262,548	5	3
All hay	322,128	2	22

Source: USDA Nat Ag Stat Service: www.nass.usda.gov/ny
From Wolfe and Comstock, forthcoming-b, p. 36-37.

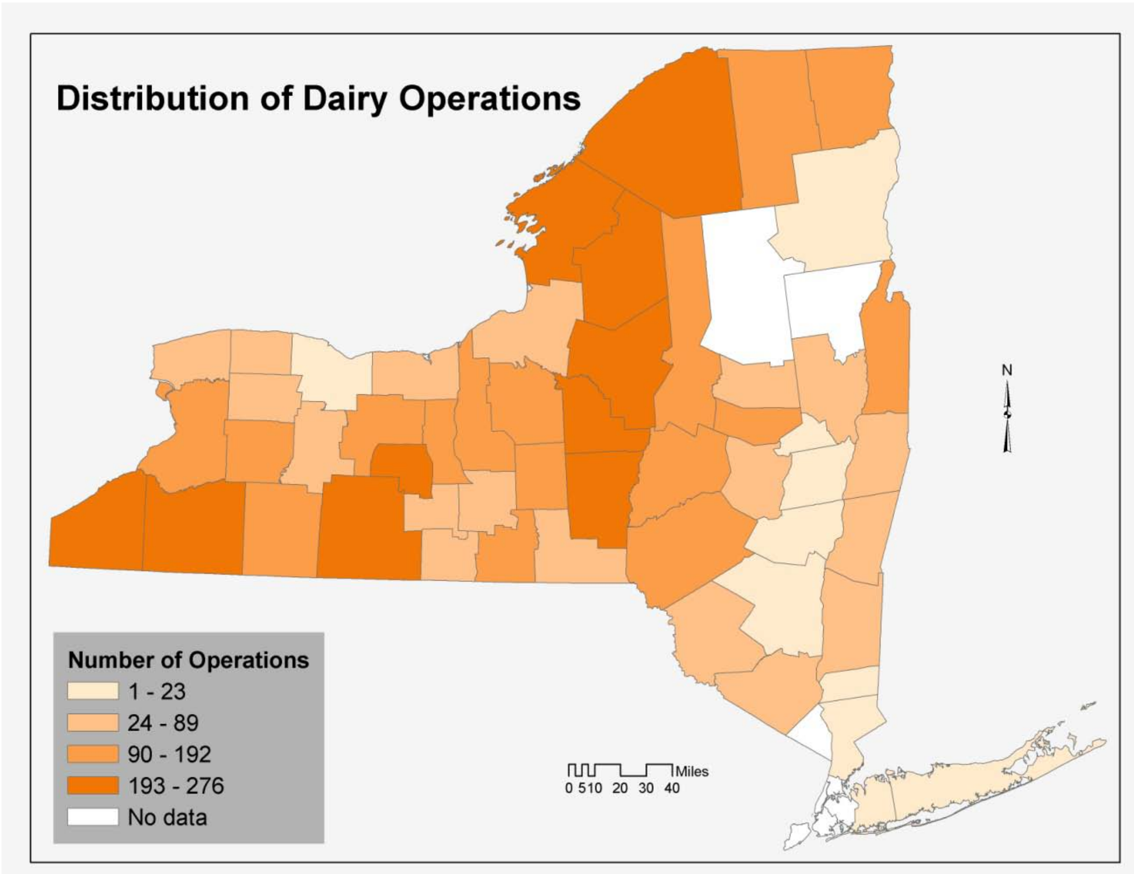

Figure 5.1. Locations of dairy operations in New York State.
Source: USDA 2009.

Approximately 56,900 people in New York State were involved in farming and ranching in 2007 as key farm operators, and almost 60,000 farm laborers were hired statewide (New York Office of the State Comptroller 2010). Within the state's food processing sector, much of which is directly tied to the state's agricultural output for activities such as canning and preserving of fruit and vegetables and dairy product manufacturing, total employment was 48,815 in 2007. Payroll in the state's food processing sector totaled more than $1.7 billion in 2007 (United States Census Bureau 2010a).

Table 5.5. Changes in NY Farm Characteristics

	1997	**2002**	**2007**
Approximate total land area (acres)	30,196,361	30,216,824	30,162,489
Total farmland (acres)	7,788,241	7,660,969	7,174,743
Cropland (acres)	4,961,538	4,841,367	4,314,954
Harvested Cropland (acres)	3,855,732	3,846,368	3,651,278
Woodland (acres)	1,655,185	1,649,585	1,559,522
Pastureland (acres)	520,150	550,225	714,615
Land in house lots, ponds, roads, wasteland, etc. (acres)	651,368	619,792	585,652
Farmland in conservation or wetlands reserve programs (acres)	97,617	211,996	115,546
Average farm size (acres)	204	206	197
Farms by size (percent)			
1 to 99 acres	45.9	47.9	51.2
100 to 499 acres	45.1	42.8	40.4
500 to 999 acres	6.7	6.6	5.5
1000 to 1,999 acres	1.9	2.2	2.1
2,000 or more acres	0.4	0.6	0.8
Farms by sales (percent)			
Less than $9,999	51.6	55.9	54.6
$10,000 to $49,999	20.7	18.5	20.4
$50,000 to $99,999	9.1	8.2	6.2
$100,000 to $499,999	15.9	14.4	14.0
More than $500,000	2.6	2.9	4.8
Farm organization			
Individuals/family, sole proprietorship (farms)	32,813	32,654	30,621
Family-held corporations (farms)	1,593	1,388	1,885
Partnerships (farms)	3,465	2,846	3,347
Non-family corporations (farms)	178	193	225
Others - cooperative, estate or trust, institutional, etc. (farms)	215	174	274

Data Source: USDA 2010 (,U.S. Census of Agriculture: 1997, 2002, 2007.
More information on farm characteristics available from the Census of Agriculture.

The value of agriculture to the state extends beyond farming and food processing. For example, New York is the second-largest producer of wine in the nation behind California, with wine sales in excess of $420 million in 2007. In 2008, the state's 208 wineries employed approximately 3,000 workers (NY State Office of the Comptroller, 2010). An analysis of the total value of the New York grape and wine industry that included multipliers such as regional tourism and supporting industries estimated that the total economic impact of this industry in 2004 was over $6 billion (MKF Research 2005).

Agricultural areas encompass about one quarter of the state's land area (over 7.5 million acres). Reduction of pollution as the result of farming practices continues to be a priority for New York State farmers. Farm landscapes also provide important and economically valuable ecosystem services such as preservation of soil and water resources, habitat to enhance biodiversity, and carbon sequestration to mitigate climate change (Bennet and Balvanera 2007) (Wolfe and Comstock, forthcoming-b). The state also has an active Farmland Protection Program. As of 2009, the state had awarded over $173 million to assist municipal and county governments and local project partners on projects in 29 counties. Upon completion, these projects will permanently protect over 72,000 acres of agricultural land (USDA NASS 2010). To date, more than 160 farmland protection projects have been completed in the state, protecting over 31,000 acres with a state investment of more than $84 million (USDA NASS 2010).

The response of New York agriculture to climate change will occur in the context of numerous economic and other forces that will be shaping its future, including pricing pressures, trends toward farm consolidation, rising energy and production costs, and increasing competition for water resources (Wolfe and Comstock, forthcoming-b). As illustrated in Table 5.5, the state's agricultural sector has undergone a number of changes over the past decade including a decline in total acres of farmland from 7.78 million in 1997 to 7.17 million in 2007, a decline in average farm size, from 204 acres in 1997 to 195 acres in 2007, and increases in the number of very small farms (under 99 acres) and very large farms (over 2000 acres). Although examination of how climate change may intersect or influence these trends is beyond the scope of the present study, it important to recognize that these broader trends will condition the impacts of climate change and the adaptation strategies available.

5.2 Key Climate Change Sensitivities

Climatic conditions are a critical driver of agricultural activity and production worldwide. A number of aspects of climate change are particularly relevant to the agriculture sector in New York State. These factors are summarized in Table 5.6 and described in detail in Wolfe and Comstock, forthcoming-b.

Table 5.6. Climate change sensitivities: Agriculture sector (See Wolfe and Comstock, forthcoming-b, for further details)

Higher atmospheric carbon dioxide (CO_2) levels can potentially increase growth and yield of many crops under optimum conditions. However, research has shown that many aggressive weed species benefit more than cash crops, and weeds also become more resistant to herbicides at higher CO_2.
Warmer summer temperatures and longer growing seasons may increase yields and expand market opportunities for some crops. Some insect pests, insect disease vectors, and pathogens will benefit in multiple ways, such more generations per season, and for leaf-feeding insects, an increase in food quantity or quality.
Increased frequency of summer heat stress will negatively affect yield and quality of many crops, and negatively affect health and productivity of dairy cows and other livestock.
Warmer winters will affect suitability of various perennial fruit crops and ornamentals for New York. The habitable range of some invasive plants, weeds, insect and disease pests will have the potential to expand into New York, and warmer winters will increase survival and spring populations of some insects and other pests that currently marginally overwinter in this area.
Less snow cover insulation in winter will affect soil temperatures and depth of freezing, with complex effects on root biology, soil microbial activity, nutrient retention (Rich 2008) and winter survival of some insects, weed seeds, and pathogens. Snow cover also will affect spring thaw dynamics, levels of spring flooding, regional hydrology and water availability.
Increased frequency of late summer droughts will negatively affect productivity and quality, and increase the need for irrigation.
Increased frequency of high rainfall events is already being observed with negative consequences such as direct crop flood damage, non-point source losses of nutrients, sediment via runoff and flood events and costly delays in field access.

5.3. Impact costs

This section discusses the potential costs associated with impacts of climate change across the major components of the state's agricultural sector. Numerous assessments of the costs of climate change on agriculture and food production have been conducted on a global level and for specific countries including the United States (e.g., Cline 2007; McCarl 2007; Parry et al. 2004). These studies typically employ methods that include either modeling of the impact of climate change on crop yields and agricultural output or estimation of how land values vary as a function of climatic conditions. In recent years, crop model assessments have also incorporated different future development scenarios based on the IPCC Special Report on Emissions Scenarios (SRES) which allow for variations in projected population, income levels, and emissions (e.g., Parry et al. 2004).

Results of these types of studies provide a 'top down' gauge of the potential costs of climate change both for the U.S. as a whole and for major subregions. A widely cited study by Cline (2007), for example, finds increases in agricultural output for the U.S. Lakes and Northeast region as the result of climate change, despite overall losses for the United States as a whole. Under a scenario that does not assume crop fertilization from CO_2, the study finds that climate change will lead to an increase in agricultural production of 5.0 percent for the Great Lakes and Northeast region by the 2080s, but that the U.S. as a whole will experience a net loss of 5.9 percent, largely due to reduced production in the Southeast and Southwest regions (Cline, 2007, p. 71).

Although these types of aggregate studies provide an indication of the direction and general magnitude of the impacts of climate change, they provide little information that is specific to key economic components of the New York's agricultural sector. As described below, climate change may have significant costs for various facets of New York State's sector, particularly if appropriate adaptation measures are not taken. Such costs, as described below, include declining yields in the dairy sector, declines in yield and quality of perennial fruit crops, and crop losses associated with drought, weeds and pests (see also Tables 5.1 and 5.2).

Heat Stress and Milk Production. Dairy is the largest component of New York State's agricultural sector. Higher temperatures and summer heat stress on dairy cattle may result in lower milk production, decreased calving, and increased risk of other health disorders – all of which impact costs and profitability. The negative economic impacts of climate change on the dairy sector are likely to be substantial without significant adaptation (Wolfe and Comstock, forthcoming-b).

Heat stress has an especially significant effect on milk production and calving rates for dairy cows. Historical economic losses due to heat stress for dairy and other livestock industries in New York have been estimated to be $24.9 million per year (St. Pierre et al. 2003, p. E70). Under climate change, higher temperature and humidity indices (THI) are likely to have a significant negative effect on total milk production. High-producing dairy cows (85lb/day) are especially sensitive to the effects of heat stress, and even small declines in dairy milk production (e.g. 2 pounds per day), translate into large losses of milk (400-500 lbs) over a lactation period. At current milk prices of $12/100 lbs, a 400-500 lbs loss would amount to $48-$60/cow (Wolfe and Comstock, forthcoming-b, Dairy case study). As average THI increases over the next century, losses are expected to increase substantially, potentially approaching 8 to 10 pounds per day during the hottest days for regular (65lb/day) and high (85lb/day) cows, respectively (Wolfe and Comstock, forthcoming-b, dairy case study).

By the 2080s, the projected annual economic losses under climate change could approach 248 lbs per year for regular cows and 437 lbs per day for high-producing cows. These losses, which represent a 6-fold increase over the historical average, would lead to economic losses of approximately $37 and $66 per cow for regular and high producing cows, respectively (Wolfe and Comstock, forthcoming-b). Assuming the total number of cows in the state in the future is relatively constant -- in 2006 there were approximately 640,000 dairy cows in New York State

(New York State, Department of Agriculture and Markets, 2007) - the value of these types of economic losses by 2080 would total more than $400 million for the dairy sector (see Table 5.2).

Climate change stresses on fruit, vegetable, and nursery crops. New York State's fruit, vegetable and nursery crops are worth approximately $807 million/year (USDA NASS 2009). Among fruit crops, perennial fruits such as apples and grapes are especially at risk from climate change. For apples, reduced winter chill periods are likely to reduce apple harvests and negatively affect fruit quality, possibly necessitating changes in apple varieties grown. Over the long term, apples may be substituted for other perennial crops, such as peaches, that are better suited to shorter winters and higher summer temperatures. In the short term, climate change is likely to have negative impact on the profitability of apple production. By contrast, grape producers in New York State are likely to benefit from climate change because warmer temperatures are more conducive to grape production. Over time, climate change may allow producers to shift to more desirable and profitable varieties for use in wine production.

Vegetable production is also vulnerable to climate change. New York currently specializes in cold-weather adapted crops such as cabbage and potatoes. Production of these types of crops is likely to decline as temperatures warm. Over time, it is likely that producers will substitute cold-weather crops with crops that are more suited to warmer growing conditions. A major economic cost for vegetable producers will entail identification of more suitable crops, purchase of seeds and capital needed to produce these new crops, and marketing of the new crops (Wolfe and Comstock, forthcoming-b).

Nursery crops are also a major industry in New York State. These high-value crops are especially vulnerable to heat stress and drought. In order to reduce present-day climate risks, the state's nursery industries are increasingly making use of controlled environments. Under climate change, the need for such environments may expand in order to cope with insects, disease, weeds, drought and heat stress.

A key climate-change related uncertainty for crop production entails changes in the frequency, timing, and magnitude of extreme events. Fruit, vegetable and outdoor nursery crop production are all highly sensitive to extreme climate events. Hail, heavy rain, and high-wind events can damage many types of crops, especially if such events occur during the growing season, and particularly near harvest time (Wolfe and Comstock, forthcoming-b). A single event during or near the harvest period, such as a brief hail storm, can virtually wipe out an entire crop in an affected region. Increased variability of temperatures during winter months is a particularly threat for perennial fruit crops. For example, during the winter of 2003-2004, mid-winter freeze damage led to substantial production losses in the Finger Lakes wine growing region. For the state as a whole, grape production declined from 198,000 tons in 2003 to 142,000 tons in 2004, with an associated loss of value of more than $6 million (USDA NASS New York Office, 2009, p. 35). These losses were primarily due to "dehardening" of the vines during an unusually warm December, which increased the susceptibility of the vines to cold damage during a subsequent hard freeze that occurred in January. (Wolfe and Comstock, forthcoming-b). Drought is also a threat to fruit and vegetable crops, the majority of which are not currently irrigated. Without adaptation, climate change-related economic losses for fruit, vegetable, and nursery crops are estimated to be nearly $230 million per year by 2080 (see Table 5.2).

Field crops and drought. Field crops such as grain and silage corn and soybeans provide a critical source of feed for the dairy and livestock sector (Wolfe and Comstock, forthcoming-b). Worth approximately $1.1 billion per year, field crops are particularly vulnerable to drought, and farmers currently incur substantial economic losses when field crops harvests are reduced or lost during drought periods. Drought related losses are likely to increase under climate change due to increased variability of summer precipitation and higher temperatures. Estimates of annual field crop losses under climate change and the benefits of adaptation, as presented in Table 5.2 above, suggest that losses under climate change may total more than $300 million by 2080 without appropriate adaptation. Such losses will directly affect feed costs for dairy and livestock farmers.

Insect damage and weeds. Higher temperatures and more CO_2 are conducive to insect reproduction and weed growth. Crop losses due to insects and weeds have been substantial in the past, and are likely to increase under climate change, without appropriate adaptations. Insect and weed pressures affect all types of crop production in New York State and costs for control of these pressures are likely to increase with climate change.

5.4 Adaptation Costs

Planning for adaptation is a critical step for New York's agricultural sector, not only in preparation for challenges such as new invasive species, but also to take advantage of warmer climates and longer growing seasons. The literature regarding the costs of adaptation within the agricultural sector generally suggests that within advanced economies such as the United States, the incremental costs of adaptation measures are likely to be relatively small in comparison with the amount that is already being invested in research and development within the sector (Wheeler and Tiffin 2009). The current literature also indicates that the need for additional, adaptation-related capital investment in the near term is likely to be less pressing than in the middle to longer term because most agricultural capital has a 10-20 year lifespan and is likely to replaced before significant climatic change impacts occur (UNFCCC, 2007, pp. 101-102). A recent top down global assessment of the total costs of climate change for agriculture estimates that adaptation in the agricultural sector will require a ten percent increase in research and development expenditure and a two percent increase in capital formation, beyond what would be spent without climate change (McCarl 2007). The costs of these additional expenditures will in the range of $11.3 to $12.6 billion globally in the year 2030, with mitigation (SRES B1) and without mitigation (SRES A1B1), respectively (Wheeler and Tiffin 2009). Another recent study, which took a "bottom up" approach by focusing on the costs for a specific type of adaptation, estimates a cost of $8 billion per year globally in 2030 for increased irrigation capacity in order to adapt climate change, under a scenario that includes mitigation (SRES B1) (Fischer et al. 2007).

Within New York State, numerous adaptations are possible in order to mitigate the impacts of climate change within the agricultural sector. While some adaptations may have negligible costs (e.g., shifting to earlier planting dates), most will entail some type of financial outlays on the part of farm operators, and some will require significant new investment. In addition to new investments will be needed, above and beyond the normal investments that would be made anyway. There is a related need for decision support tools to help farmers decide when to make investments in appropriate adaptation technologies. This section discusses costs and benefits associated with some key adaptation options for the sector. Many of these adaptations are steps that individual farmers may take, while others would require state-level involvement and coordination.

Reduction of heat stress for dairy cows. Adjustment of diet and feeding management can reduce some of the impacts of heat stress with minimal impacts on production costs. However, as temperatures increase under climate change, improvement of cooling capacities and dairy barns will be a critical adaptation in order to reduce heat stress and maintain productivity. Farmers can enhance cooling via increased use of existing fans, sprinklers, and other cooling systems (Wolfe and Comstock, forthcoming-b). The major costs for these types of adaptations would include additional energy usage and additional labor. Improvement in the cooling capacity of housing facilities is also likely to be needed, especially as average THI increase under climate change. While such systems represent added costs, these investments have a high likelihood of paying for themselves, through increased milk production, over a short time span (1 to 3 years depending on the numbers of days that the system is in operation) (Turner, 1997). For example, installation of a tunnel ventilation system for a small, 70-cow herd producing 75 lb per cow is estimated to cost $7,694 ($110/cow), including both operational costs and interest on a 5-year loan (Wolfe and Comstock, forthcoming-b). For the sector as a whole, the costs of addition and operation of cooling systems for the dairy sector are estimated to total approximately $5 million/year by the 2050s (see Tables 5.1 and 5.2).

Diversification of fruit crops and vegetable crops. Near term adaptations to climate change for fruit and vegetable producers will entail adjustments to planting or harvesting dates to coincide with early onset of spring or later occurrence of the first frost. While such steps have minimal cost, availability of labor and market demand will be critical limiting factors. As climate change progresses, farmers will need to consider new crop varieties that are more heat or drought tolerant, and may also shift to different crops that are more suitable to new climatic conditions. The costs associated with shifting crops typically include new planting or harvesting equipment and new crop storage facilities. In the case of fruit trees, it typically takes several years for a new tree to bear fruit, which also adds to the costs of adaptation.

Insect and weed control. Increase use of chemical inputs and non-chemical techniques will be a necessary adaptation in order to control increased insect, pathogen, and weed pressures under climate change. For crops such as sweet corn, the number of insecticide applications that are needed could double or even quadruple. Current climate conditions in New York require 0 to 5 insecticide applications against a key sweet corn pest (lepidopteran insects), while states with warmer climates such as Maryland and Delaware require 4-8 applications and Florida requires

15-32 applications (Wolfe and Comstock, forthcoming-b). Because chemical use is expensive and harmful to human and ecosystem health (e.g., New York potato farmers currently spend between $250 and $500 per acre for a total of $5 to $10 million statewide on fungicides to prevent late blight, [Wolfe and Comstock, forthcoming-b]), other means of adaptation to control insects and weeds will also be needed. Integrated pest management techniques are an effective means of controlling insects that minimize the use of chemical inputs. Within New York, the annual budget for state's Integrated Pest Management Program is approximately $1,000,000 (NYSIPM 2010). Such a program would likely need to be continued and substantially expanded in order to facilitate adaptation to climate change.

Irrigation and/or drainage systems. Expansion of irrigation capacity and drainage systems may be necessary in order to maintain productivity and allow farmers to take advantage of new opportunities under warmer climatic conditions. While expanded use of existing irrigation systems is possible for some farmers, installation of new systems requires significant capital investment. These systems currently draw water from local streams, but it also possible that they may require more extensive and costly infrastructure to enable water transfers between basins. The fixed capital costs associated with adding an overhead moveable pipe irrigation system within New York state are estimated to be on the order of $1000 per ha or $405 per acre (Wilks and Wolfe, 1998) (1 ha = 2.47 acres), a figure slightly higher than the nationwide estimate of approximately $290/hectare or $117/acre (Fischer et al. 2007). This type of system also requires labor costs to move the pipes with each irrigation, as well as energy costs for pumping the water. The estimated annual irrigation and annual labor costs associated with energy use are estimated to be approximately $12.50/ha ($5.06/A) and $32.50/ha ($13.16/A) respectively (not adjusted into constant dollars; Wilks and Wolfe, 1998).

Given the relatively high cost of irrigation, it is expected that such systems would only be put into place as an adaptation to climate change for production of high value fruit, vegetable, and horticulture crops. In 2007, approximately 1.5 percent of New York State's million acres were irrigated (U.S Department of Agriculture, 2009). This translates into approximately 68,000 irrigated acres (USDA 2009). During 2008, approximately half of the state's total irrigated acreage was irrigated including approximately 20,158 acres of fruit, vegetables, and other food crops and 8,765 acres of non-food horticultural crops (USDA 2010). A key reason for reduced irrigation in 2008 was adequate soil moisture (USDA 2010).

If we assume total irrigated acreage capacity in New York State would need to double for high value crops in order to adapt climate change, we can estimate both the fixed costs and variable costs associated with adding this new capacity as well as the added benefits. Table 5.7 presents estimates of both the fixed and variable costs associated with a doubling of irrigation capacity for vegetables, orchards and berries, and nursery stock, as well as the benefits associated within increased crop yields. Benefits associated with increase in yields are based on the results of Wilkes and Wolfe (1998). Wilkes and Wolfe (1998) found that addition of irrigation increases the annual per hectare value of lettuce production in New York State by more than 50 percent, from $8000/hectare to $12,500/hectare. In addition to benefits associated with increased drought resilience, which might entail preservation of much of the value of a particular crop during a drought year, added benefits from irrigation of fruits and vegetables include higher total yields and improved quality. Results indicate that fixed costs associated with the doubling of irrigation capacity for these three crop categories would be approximately $19.6 million and the labor, energy and interests costs assuming a five year loan would be an additional $1,861,000 annually. Benefits of the adding irrigation capacity for these three crop categories are estimated to be approximately $33.2 million per year in added value of crop production.

Table 5.7. Benefit Cost Analysis of Potential Climate Change Adaptation: Expansion of irrigation

Crop	Total Acres (2007)	Irrigated Acres (2007)	Percent irrigated	Annual value of crop (2007) ($M)	Fixed costs to double total acres irrigated ($M)	Annual labor, energy and interest cost of additional irrigation ($M)	Increased annual value with added irrigation ($M)
Vegetables	160,146	34,170	21.3	$338	$13.8	$1.4	$18.0
Orchards and berries	104,349	11,038	11.0	$368	$4.5	$0.4	$9.7
Nursery stock (open)	14,638	3,161*	21.6	$101	$1.3	$0.1	$5.5
Total				$807	$19.5	$1.9	$33.2

**2008 data*
Data sources: USDA 2010; U.S. Census of Agriculture, Farmer and Ranch Irrigation Survey 2008; Authors' calculations.

Research, monitoring, extension, and decision support tools. Within the agriculture sector, effective adaptation to climate change will require monitoring of new threats (e.g., new pathogens or invasive species) and extension assistance to facilitate successful transitions to new crop varieties and new crops. These types of monitoring and extension efforts can also be accompanied by development and dissemination of decision support tools. Such tools can assist farmers in making strategic adaptation choices, particularly with respect to the timing of new capital investments in adaptation such as new cooling facilities for dairy farms.

5.5 Summary and Knowledge Gaps

The broad findings for New York State agriculture echo the general findings from the literature regarding the costs of impacts and adaptation within the agricultural sector, which suggest that appropriate adaptation measures can be expected to offset declines in projected yields for the next several decades (e.g., McCarl 2007; Agrawala et al, 2008; Parry et al. 2009). Although the costs of such measures will not be insignificant, they are likely to be manageable, particularly for larger farms that produce higher value agricultural products. Smaller farms, with less available capital, may require adaptation assistance in the forms of grants or loans, in order to facilitate adaptation. Expansion of agricultural extension services will also be necessary in order to assist farmers with adaptation to new climatic conditions.

In order to facilitate adaptation in New York State, key areas for additional investment in research and extension include:

- Monitoring of new pests, weeds and other disease threats to agricultural crops;

- Improvement of techniques for integrated pest management to deal with these new threats, while minimizing use of pesticides, herbicides and other hazardous materials;

- Improvement of techniques for integrated pest management to deal with these new threats, while minimizing use of pesticides, herbicides and other hazardous materials;

- Investigation of alternative irrigation technologies that are less water and energy intensive; and

- Development of decision support tools to help farmers select and time new capital investments in order take advantage of opportunities associated with climate change, while minimizing risks.

Technical Notes – Agriculture Sector

1. Current value of production, based on the Census of Agriculture, 2007, is $2.4 billion in the dairy and livestock sector, $807 million in fruits, vegetables and nursery crops, and $1.1 billion in field crops (most of which are used as feed for dairy and livestock). Agricultural value in New York State is projected to grow by a rate of between 1.0 and 2.0 percent per year (all calculations above are based on an average growth rate of 1.5%/year). A lower rate of growth is used in this sector as compared to the state overall because the agriculture sector has been growing more slowly than other facets of the state's economy and limits on land availability are likely to constrain future growth.

2. Dairy sector estimates are based on costs of heat stress on milk production assuming changes in diet but no additional cooling capacity in dairy barns (see Wolfe and Comstock, forthcoming-b, Table 7.5). The estimated cost of adaptation are based on costs of addition and operation of cooling systems for dairy barns, assuming costs per cow range from $10 to $110 (see Wolfe and Comstock, forthcoming-b, Dairy case study). With adaptation, the effects of heat stress on dairy production are expected to be reduced by 50%. (This is the assumed benefit of adaptation.)

3. Current annual climate-related losses for fruit, vegetables and nursery products are assumed to range from approximately 1.0 to 2.5 percent/year of the total value. Without adaptation, projected values are assumed to decline by 1.0% in 2020, 5% in 2050 and 10% in 2080. With adaptation, the net effects of climate change are expected to be positive due to both longer growing season and on-farm adaptations (e.g. irrigation, changing crop varieties, pest control). Gains of 1% in 2020, 2.5% in 2050, 5.0% in 2080, are based Cline (2007). Cline (2007) estimates of 5% gain by 2080 in agricultural productivity for the U.S. Northeast, without assuming CO_2 fertilization. Values for 2020 and 2050 were estimated based on extrapolation. The benefits of adaptation are calculated by subtracting the total value of production under climate change without adaptation from the total value of production with adaptation.

4. Current annual climate-related losses for field crop products are assumed to range from approximately 1.0 to 5.0 percent/year of the total value. Projected values are assumed to decline between 1% and 5% in 2020 and 2050, and between 5% and 10% in 2080 without adaptation. With adaptation, the net effects of climate change are expected to be positive due to both longer growing season and on-farm adaptations (e.g., changing crop varieties, pest control). Gains of 1% in 2020, 2.5% in 2050, 5.0% in 2080, are based Cline (2007), as described above. The net benefits of adaptation are calculated by subtracting the total value of production under climate change without adaptation from the total value of production with adaptation.

6 Energy

New York State's electricity and gas supply and distribution systems are highly reliable; they are designed to operate under a wide range of temperature and weather conditions – from 0 to 100˚F, in direct sunlight or under the weight of snow and ice. The system is deliberately robust and resilient because utility companies are risk averse. When designing energy supply and distribution systems companies use conservative engineering estimates (industry standards plus 30%) and typically look 20 years into the future. In some cases, threshold conditions (as opposed to the mean or standard conditions), or shifts in the threshold caused by climate change can create vulnerability within the energy sector (Hammer, 2010) and substantially increase the cost of maintaining reliability.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR ENERGY SECTOR

Key Economic Vulnerabilities

This section provides estimates of the extent to which climate related changes will affect economic components of the energy sector. Table 1 identifies the climate variables that are likely to impact the sector along with the project economic outcome. Note that economic risks significantly outweigh opportunities.

Table 6.1. Climate and Economic Sensitivity Matrix: Energy Sector (Values in $2010 US.)

Element	Main Climate Variables: Temperature	Main Climate Variables: Precipitation	Main Climate Variables: Sea Level Rise	Main Climate Variables: Extreme Events: Heat	Main Climate Variables: Extreme Events: Intense Precipitation	Main Climate Variables: Extreme Events: Hurricanes, Nor'easters, & Wind	Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
Energy Supply	●	●	●				– Changes in biomass available for generation – Availability of hydropower reduced – Potential Changes in solar exposure – Availability and predictability is reduced with variation in wind – Reduced water cooling capacity – Damage to coastal power plants – Sagging power lines – Wear on transformers – Transmission infrastructure damage – Transmissions lines sagging due to freezing/collecting ice	$36-73M	Costs: $19M Benefits: $76M
Electricity Demand	●		●	●			– Increased energy demand for cooling – Increased demand for pumping at coastal energy producing locations – Potential increases in pumping for industrial cooling water – Decreased demand for winter heating	Increased supply costs	Net total of increased air conditioning use in summer and heat in winter and pumping demands
Buildings				●	●	●	– Heightened storm regime may reveal weaknesses in building envelopes – Low-lying areas susceptible to more frequent flooding + Installation of green roofs	Structural damage from extreme events; Increased insurance costs	Cost for repairs and upgrades
Total estimated costs of key elements								$37-73M	Costs: $19M Benefits: $76M

Key for color-coding:

	Analyzed example
	From literature
	Qualitative information
	Unknown

For the energy sector, climate change will affect both energy supply and energy demand.

Energy Supply

Milder winter weather may help alleviate some of the stresses on the supply chain of New York State's energy system, however it is more commonly projected that climate change will adversely affect system operations, increase the difficulty of ensuring supply adequacy during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect (Rosenzweig and Solecki, 2001). The following climate impacts pose the greatest economic risks and vulnerabilities to energy supply:

Impacts on thermoelectric power generation and power distribution due to floods and droughts, increases in air and water temperatures, and ice and snow storms. The threat of ice storms affecting upstate energy infrastructure is potentially large (Hammer, 2010). Additionally, sea level rise and storm surges will threaten coastal power plants.

Impacts on natural gas distribution infrastructure due to the flood risk associated with extreme weather events (Associated Press 1986, New York Times 1994), and frost heaves (Williams and Wallis, 1995) (although the effect that climate change will have on frost heaves is still unclear). These potential impacts would be alleviated to some extent because natural gas supplies adequate to provide some level of insurance against natural disasters that may disrupt production and delivery systems are stored in underground facilities in western New York and Pennsylvania (Hammer and Parshall, forthcoming).

Impacts on renewable power generation due to changes in the timing and quantity of the natural resource available for power generation (Hammer and Parshall, forthcoming). For example, the lost capacity for inexpensive hydropower may be replaced by more expensive forms of power generation, creating significant cost repercussions for the state (Morris et al., 1996).

Energy Demand

The following climate impacts pose the greatest economic risks and vulnerabilities to energy demand:

Shifts in the number of heating degree-days and cooling degree-days (i.e. demand space for heating and cooling) will occur due to changes in mean and extreme temperatures. The direction and magnitude of changes in energy demand depend on changes in heating and cooling degree-days, other climate shifts, and the sensitivity of demand to climate factors

(Hammer and Parshall, forthcoming). As electricity consumption climbs and peak demand grows in summer months, the current energy supply and demand equilibria will be disrupted. With higher mean temperatures and increased numbers of extremely hot days, the cost of maintaining a reliable supply of electricity is likely to increase in all parts of the state. For New York City in particularly, where the system is already taxed during very hot summer days, climate change will place additional pressures. Meeting the demand for electricity may also become more expensive due to extreme weather events (The Center for Integrated Environmental Research, 2008, p. 4). There may also be increases in demand for industrial uses due to changing climate, for example increases in pumping cooling water for industrial uses. Changes in incomes, technology, law and population will probably result in greater impacts on energy demand than climate change. The energy sector, among the ClimAID sectors, is perhaps the most likely to see game-changing policies in the next decade. For example, a carbon tax in any form (either directly, or indirectly through cap-and-trade) could radically alter demand and supply conditions in the energy sector.

To the extent that climate change causes additional economic impacts on the sector, these are likely to be for increased capacity and smarter grids. There is also the possibility of increased climate-related blackouts due to increased demand. This possibility depends on the level of investment within the energy sector. There are regular, ongoing new investments in the sector that will continue to be undertaken even without specific new programs for adaptation to climate change; to the extent that these contribute to a more stable system under both present and future climate conditions, blackouts will be reduced. (If the electrical system becomes hardened against electromagnetic storms, that will go even further to accommodate the impacts of climate change.) However, the potential uncertainty in the pattern and extent of extreme heat events could increase outages, although fewer than would be expected absent the ongoing improvements in system reliability that can be assumed. Even with regularly improved systems, therefore, the probability is that some additional adaptations will be needed that specifically take climate change into account, particularly to handle extreme heat; some utilities are already beginning to incorporate climate change into their planning processes. The possibility of a slightly increased incidence of blackouts can be used to illustrate the costs of climate change in the energy sector if such adaptation measures are not undertaken.

As the likelihood of a blackout is exacerbated by heat waves and associated thunderstorms (as well as other extreme storm events), and as heat waves are likely to increase in the future, it is likely that blackouts may occur somewhat more frequently, although to an extent reduced by the regular, ongoing investment of the electricity industry. A study by the Wharton School (2003) indicates that the energy system is designed for a 1-in-10 year blackout, over the past thirty years New York City has experienced four major events in 1977, 1999, 2003 and 2006. Climate change could, without ongoing investment, increase the number of blackouts above that for which the system is designed. Cost estimates vary widely from these events, as it can be difficult to ascertain exact expenses directly related to the blackout. However, using a range of estimates, it is possible to calculate an average cost per event. From this estimate, based on the assumption that a blackout occurs once every ten years, an annual cost can be obtained. Using the heatwave projections given in Horton et al. (forthcoming) future cost of impact estimates can be estimated based on these assumptions and the impacts of regular upgrades in investment.

One key adaptation put forward to reduce the likelihood of heat-related blackouts is the installation of a smart grid, as discussed in the adaptation section of this chapter. Additionally, the Multi-hazard Mitigation Council has estimated that every $1 spent in public disaster mitigation results in a $4 savings. Based on these findings an approximate adaptation cost and benefit calculation can be estimated. These calculations are shown in Table 6.2.

Table 6.2. Energy sector illustrative key impacts and adaptations (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)	Annual incremental costs of climate change impacts, without adaptation ($M)	Annual costs of adaptation ($M)	Annual benefits of adaptation ($M)
Heat related blackout	Baseline[1]	$18	-	-7	-26
	2020s	$21	$10 - $22	$9	$37[2]
	2050s	$36	$36 - $73	$19	$76
	2080s	$62	$92 - $206	$38	$154

Notes: The relationship in the tables is not exact due to rounding in calculations. See Technical Notes at the end of the chapter for complete methodology.

[1] The baseline is based on the cost estimates from blackouts that occurred during the 30-year period from 1966 to 2006, where blackouts occurred in 1977, 1999, 2003, and 2006. All costs were indexed to 2006 values. Blackout costs based on New York City blackouts; scaled up by 3 to produce a state-wide estimate.

[2]Based on the findings by the Multi-hazard Mitigation Council (2005a) that every $1 spent in public disaster mitigation results in a $4 savings in non-incurred disaster losses (see also the references in Jacob et al., forthcoming-a).

Results

Based on the range of estimates from the previous four major blackouts in New York City, indexed to current value and scaled up to New York State, a baseline annual cost of historic heat-related blackouts was found to be $16 million. Assuming no changes in the current climate, this estimate was scaled up with a 2.4% GDP growth rate to find estimates for the midpoints of the 2020s, 2050s, and 2080s. These results were $27 million for the 2020s, $54 million for the 2050s and $111 million for the 2080s. The costs from impacts assuming a change in current climate were then imposed on these values based on the projections of the increase in heatwaves from the Horton et al. (forthcoming). Without adaptation, the estimated annual incremental costs of heat-related blackouts above the baseline estimates were estimated at $13 to 27 million for the 2020s, $54 to 110 million for the 2050s and $161 to 332 million for the 2080s. As explained in the Technical Notes, both the extrapolated without climate change and extrapolated with climate change figures are reduced because of assumed regular, ongoing investment by the energy sector, so that the number of blackouts per heatwave declines over time. In any event, better climate projections will assist the utilities in their planning both for climate and other drivers of energy demand.

If, however, a smart grid system is installed and maintained in New York State, these costs are reduced significantly. For the calculations, it is assumed that one-half of the cost of the smart grid is for climate change; the other half is assumed to be part of regular investment by the energy sector. Additionally, better climate projections will assist utilities in incorporating the changing climate into their planning processes.

PART II. BACKGROUND

6.1 Energy in New York State

This section describes the most important economic components of the energy sector with respect to value at risk to climate change. Energy supply and demand projections for a twenty-year time frame are emphasized in the discussion below. For longer time frames, there are substantial uncertainties associated with the pace of technological change and the development of alternative forms of energy, as well as shifts in the policy and regulatory environment. While this report assumes a GDP growth rate of 2.4 percent for New York State over the next century, is also important to realize that rates of population and economic growth are also uncertain and will have substantial impacts on both energy supply and demand. Taken together, technological changes, policy changes, and rates of growth in demand are likely to be more significant drivers or change of the energy sector than climate change.

The energy sector is generally very risk averse, utilizing a short term planning horizon, conservative engineering estimates, and acting only on reliable information. The risk and probability divisions within utility companies handle climate change, and they are essentially making a bet on the level of climate change that might occur. Utilities hesitant to make investments in this area are concerned with recovering adaptation costs and realize that customers might not want to bear the costs to create a more responsive energy system that would protect against threshold climate conditions (Hammer, 2010).

State GDP and Employment

The size of the energy sector is reported almost exactly in the official State GDP figures issued by the U.S. Bureau of Economic Analysis. The main NAICS classification for energy is Utilities, and the subsidiary parts are: Electric Power Generation, Transmission, and Distribution, Natural Gas Distribution, and Water, Sewage, and Other Systems. (The ClimAID energy sector does not include Water, Sewage, and Other Systems.) New York State has substantial components in each of these. For the 2008 current dollar State GDP figures, New York State GDP was $1.144 trillion; of this total, $20.914 billion was in the utilities sector.

6.2 Key Climate Change Sensitivities

Changes in temperature, precipitation, extreme events, and sea level are anticipated to have adverse effects on energy resources, generation assets, transmission and distribution assets, electricity demand, and buildings. "Weather-related stressors can damage equipment, disrupt fuel supply chains, reduce power plant output levels, or increase demand beyond operational capacity," (Hammer and Parshall, forthcoming). This section specifies which facets of climate change will impact the key economic components of the energy sector (Table 6.3). See also Summary of climate risks to New York energy system; Hammer and Parshall, forthcoming.

Table 6.3. Climate Change Sensitivities: Energy Sector

Increases in mean temperature will affect the thermal efficiency of power generation, change the amount of biomass available for energy generation, alter the water-cooling capacity at power plants, lead to a rise in energy demand, and cause power lines to sag and wear on the transformers. Electrical lines and transformers will fail more often as energy demands exceed the equipments rated capacity.
Increases in extreme heat events and decreases in cold events will change electricity demand patterns and may overwhelm the power supply system in times of summer peak energy demand.
Increases in mean precipitation will reduce the availability and reliability of hydropower generation, as they are dependent upon the timing and quantity of precipitation and snowmelt.
Increases in intense precipitation events will make building and homes more susceptible to flooding, creating the potential of structural damage to boilers.
Snow and ice will damage transmission lines, causing them to sag.
Hurricanes, nor'easters, and extreme winds will damage buildings and energy infrastructure and cause power outages. Extreme weather events may also change energy demand patterns.
Sea level rise will damage coastal power plants.

6.3 Impact Costs

Climate change is anticipated to impact the energy sector in two ways: first, energy demand will change due to a different combination of heating and cooling needs, and second, the physical structures (power plants, electrical lines, etc.) will be affected by changing climate conditions (Dore & Burton, 2000, p. 78). Additional indirect impacts on the energy sector, such as the financial impacts on investors or insurance companies linked to vulnerable energy system assets or on customers forced to grapple with changing energy prices resulting from changing climate conditions, should not be forgotten as they may even be greater than the direct impacts (Hammer and Parshall, forthcoming). The following section presents the costs of climate change impacts for New York State, which are primarily incurred through outages, power prices, loss of income to the utility companies, benefit transferred to the consumer, and additional research.

Power Outages

Economic losses from electric service interruptions are not trivial, as indicated by estimates of damage costs ensuing from major power outages, which may occur during periods of increased energy demand, such as heat waves. The economic impact of the 25-hour blackout that affected most of New York City in July 1977 was assessed at $60 million (estimate may include costs of riots and looting), while the cascading blackout of August 14, 2003 has been estimated to affect approximately 22,000 restaurants, which lost from $75 million to $100 million in foregone business and wasted food. In addition, the City of New York reported losses of $40 million in lost tax revenue and $10 million in overtime payments to city workers (Wharton School 2003).

Other localized service outages in New York City include the July 3-9, 1999 blackout that affected 170,000 Con Edison customers, including 70,000 in Washington Heights (New York State Public Service Commission, 2000); as well as the nine-day blackout that started on July 16, 2006 in Long Island City, Queens, which affected 174,000 residents (Chan 2007). Total claims paid by Con Edison in 2006 amounted to $17 million ($350 to compensate residents and $7,000 to business customers); and an additional $100 million was estimated to be spent by the utility on recovery costs to repair and replace damaged equipment (Office of the Attorney General, 2007). Preventing the losses described above, as well as the number of mortality cases due to heat stress, will require further strengthening of the reliability of the electric grid in order to decrease the number of power outages (paragraph based on Leichenko et al. forthcoming).

Additional analogous impact costs for the energy sector outside NY include:

- In 1998, a massive multi-day ice storm resulted in more than $1 billion in damage across the northeastern United States and eastern Canada. In New York State alone, dozens of high-voltage transmission towers, 12,500 distribution poles, 3,000 pole-top transformers and more than 500 miles of wire conductor required replacement, affecting 100,000 customers from Watertown to Plattsburgh. Most of the repairs were completed within two months, although some areas were not completely repaired for four months (Hammer and Parshall, forthcoming).

- A 2001 survey report found that the estimated cost to US consumers of business losses was between $119 billion to $188 billion per year due to poor power quality, outages and other disruptions (referred to collectively as "reliability events"). The Pacific Gas & Electric Company used direct costs of reliability events to assess that such power disruptions cost its customers approximately $79 billion per year. A 2004 Berkeley National Laboratory comprehensive study of end-users focusing on just power outages, estimated annual losses to the national economy of approximately $80 billion. The figures provided by these studies coincide with estimates by the US Department of Energy, ranging from $25 billion to $180 billion per year (Hammer and Parshall, forthcoming).

- A 2006 IJC report examining alternatives to the 1958-D Order of Approval estimated that the economic impact on hydropower production at NYPA's St. Lawrence/FDR project could vary from -$28.5 million to $5.86 million, depending on which GCM is employed. (The "not-so-warm/wet" scenario was the only one of the four models to produce a positive impact.) The NYPA has developed its own internal estimate, however, that a 1 meter decrease in the elevation of Lake Ontario would result in a loss of 280,000 MWh of power production at the St. Lawrence/FED project (Hammer and Parshall, forthcoming)

The information summarized in the tables below shows the impact costs of power outages and disruptions. Large commercial and industrial customers will experience losses averaging $20,000 and $8,166 for a 1-hour power interruption during a winter afternoon and summer afternoon, respectively. As the power outage increases in duration, so do costs – sharply during the winter and significantly in the summer (Hammer and Parshall, forthcoming).

The total economic cost of a blackout can be estimated by multiplying the affected customers' average value of electricity by data on the magnitude and duration of the power outage. Based on previous analyses, ICF Consulting estimated that the value assigned by consumers to electric power service reliability is on average 100 times its retail price (or a range from 80 to 120 times the retail price). In the case of the 2003 blackout, and assuming a total outage period of 72 hours and using the average electricity price for the region of $93/MWh, the economic cost to the national economy was estimated to be between $7 and $10 billion (Hammer and Parshall, forthcoming).

Table 6.4. Estimated Average Electric Customer Interruption Costs Per Event US 2008$ by Customer Type, Duration and Time of Day

	Interruption Duration				
Interruption Cost	Momentary	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I					
Morning	$8,133	$11,035	$14,488	$43,954	$70,190
Afternoon	$11,756	$15,709	$20,360	$59,188	$93,890
Evening	$9,276	$12,844	$17,162	$55,278	$89,145
Small C&I					
Morning	$346	$492	$673	$2,389	$4,348
Afternoon	$439	$610	$818	$2,696	$4,768
Evening	$199	$299	$431	$1,881	$3,734
Residential					
Morning	$3.7	$4.4	$5.2	$9.9	$13.6
Afternoon	$2.7	$3.3	$3.9	$7.8	$10.7
Evening	$2.4	$3.0	$3.7	$8.4	$11.9

Source: (Hammer and Parshall, forthcoming).

Table 6.5. Estimated Average Electric Customer Interruption Costs Per Event US 2008$ by Duration and Business Type (Summer Weekday Afternoon)

Interruption Cost	Interruption Duration				
	Momentary	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I					
Agriculture	$4,382	$6,044	$8,049	$25,628	$41,250
Mining	$9,874	$12,883	$16,366	$44,708	$70,281
Construction	$27,048	$36,097	$46,733	$135,383	$214,644
Manufacturing	$22,106	$29,098	$37,238	$104,019	$164,033
Telecommunications & Utilities	$11,243	$15,249	$20,015	$60,663	$96,857
Trade & Retail	$7,625	$10,113	$13,025	$37,112	$58,694
Fin., Ins. & Real Estate	$17,451	$23,573	$30,834	$92,375	$147,219
Services	$8,283	$11,254	$14,793	$45,057	$71,997
Public Administration	$9,360	$12,670	$16,601	$50,022	$79,793
Small C&I					
Agriculture	$293	$434	$615	$2,521	$4,868
Mining	$935	$1,285	$1,707	$5,424	$9,465
Construction	$1,052	$1,436	$1,895	$5,881	$10,177
Manufacturing	$609	$836	$1,110	$3,515	$6,127
Telecommunications & Utilities	$583	$810	$1,085	$3,560	$6,286
Trade & Retail	$420	$575	$760	$2,383	$4,138
Fin., Ins. & Real Estate	$597	$831	$1,115	$3,685	$6,525
Services	$333	$465	$625	$2,080	$3,691
Public Administration	$230	$332	$461	$1,724	$3,205

Source: (Hammer and Parshall, forthcoming).

Table 6.6. Estimated Average Electric Customer Interruption Costs Per Event US 2008$ by Customer Type, Duration, Season and Day Type

Outage Cost	Outage Duration				
	Momentary	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I					
Summer Weekday	$11,756	$15,709	$20,360	$59,188	$93,890
Summer Weekend	$8,363	$11,318	$14,828	$44,656	$71,228
Winter Weekday	$9,306	$12,963	$17,411	$57,097	$92,361
Winter Weekend	$6,347	$8,977	$12,220	$42,025	$68,543
Small C&I					
Summer Weekday	$439	$610	$818	$2,696	$4,768
Summer Weekend	$265	$378	$519	$1,866	$3,414
Winter Weekday	$592	$846	$1,164	$4,223	$7,753
Winter Weekend	$343	$504	$711	$2,846	$5,443
Residential					
Summer Weekday	$2.7	$3.3	$3.9	$7.8	$10.7
Summer Weekend	$3.2	$3.9	$4.6	$9.1	$12.6
Winter Weekday	$1.7	$2.1	$2.6	$6.0	$8.5
Winter Weekend	$2.0	$2.5	$3.1	$7.1	$10.0

Source: (Hammer and Parshall, forthcoming).

Table 6.7. Value of Service Direct Cost Estimation

Facility Outage Impacts			Annual Outages		Annual Cost	
Power Quality Disruptions	Outage Duration per Occurrence	Facility Disruption per Occurrence	Occurrences per Year	Total Annual Facility Disruption	Outage Cost per Hour*	Total Annual Costs
Momentary Interruptions	5.3 Seconds	0.5 Hours	2.5	1.3 Hours	$45,000	$56,250
Long-Duration Interruptions	60 Minutes	5.0 Hours	0.5	2.5 Hours	$45,000	$112,500
Total			3	3.8 Hours		$168,750
Unserved kWh per hour (based on 1,500 kW average demand)			1,500 kWh			
Customer's Estimated Value of Service (VOS), $/unserved kWh			$30 /unserved KWh			
Normalized Annual Outage Costs, $/kW-year			$113 $/kW-year			

Source: (*Hammer and Parshall, forthcoming*).

6.4 Adaptation Costs

Adaptation costs in the energy sector are positively correlated with the level of temperature increases and economic growth (Dore & Burton, 2000, p. 79). In addition to temperature change, other important factors that influence economic costs in the energy sector include population growth projections, fuel price changes, and the GDP (Dore & Burton, 2000, p. 80). However, current literature on adaptation costs is primarily focused on increases in energy demand for cooling in the summer and reduced heating in the winter (Agrawala et al, 2008, p. 56). Many studies have concluded that for the United States the adaptation costs of increased cooling will be greater than the benefits of reduced heating demands **(**Agrawala et al, 2008, p. 57-58). An overview of adaptation possibilities in the energy sector is in AAC (2010), pp. 88-91. Some estimates of the costs of climate change adaptation strategies relevant to New York State are given in the following paragraphs.

The existing power system infrastructure in the US was recently valued at $800 billion (Hammer and Parshall, forthcoming). Because this system requires constant refurbishment and eventual replacement over long timescales, it will make sense to align implementation of adaptation measures into the natural replacement cycle of vulnerable system assets.

Adaptation strategies generally target either supply or demand. Supply related measures often emphasize physical improvements to enhance the capacity of power generation, transmission, and distribution to better operate under a range of future climate conditions. Demand related measures target all types of energy consumption, from taxes to public education programs (Hammer and Parshall, forthcoming).

Out of the numerous adaptation strategies presented, Hammer and Parshall (forthcoming) have identified NYSERDA as a stakeholder in the position to implement the following measures:

Energy Supply

- Install solar PV technology to reduce effects of peak demand
- Develop non-hydro power generation resources to reduce need for hydropower generation during winter

Energy Demand

- Design new buildings with improved flow-through ventilation to reduce air conditioning use
- Increase use of insulation in new buildings and retrofit existing buildings with more insulation and efficient cooling systems
- Improve information availability on climate change impacts to decision makers and public
- Plant trees for shading and use reflective roof surfaces on new and existing buildings
- Install power management devices on office equipment
- Upgrade building interior and lighting efficiency
- Improve domestic hot water generation and use
- Improve HVAC controls
- Upgrade elevator motors and controls
- HVAC design improvements
- More efficient HVAC equipment
- Improved steam distribution
- Weatherize low income households

The costs of several adaptations are as follows:

Saltwater Resistant Transformers

Con Edison voluntarily launched a 10-year plan beginning in 2007 to replace 186 underground transformers located in Category 1 floodplains around NYC for a cost of $7 million. New saltwater submersible transformers can better handle storm surge intrusion than the equipment currently in place (Hammer and Parshall, forthcoming; New York State Department of Public Service, 2007). However, utility companies can be reluctant to install more of these transformers if they think that they will be unable to recover the costs through higher rates.

Back-up Generators

The energy grid may change over time to more distributive power (Hammer, 2010). Gridpoint's Connect Series unit, a battery back-up system for houses, is a step in this direction. The unit costs around $10,000 and is the size of a refrigerator. It has the capacity to store 12kWh of usable AC electricity and helps electricity utilities and customers manage energy more intelligently. Telecommunication grade lead acid batteries are used in the unit, which last for five years and cost about $185 per usable kilowatt-hour of AC current.

The benefits of distributive storage include reliable constant power, even during power outages, because stored electricity can be discharged back into the grid beyond the break line. Also, electricity can be stored during low off peak rates and discharged when rates are higher in markets where energy pricing is tiered. Distributive power can even flatten the electricity load and relieve congestion on the grid by pushing power into the grid during peak hours of demand from distributed sources. Distributed renewable energy sources, i.e. wind and solar, can be captured by the storage system during their limited hours of collection and utilized at any time (EcoWorld, http://www.ecoworld.com/technology/gridpoints-storage.html).

Smart grid. Smart grid technology provides operators with the information necessary to properly manage power flows and transmission systems by creating a clearer metric of potential risk to avoid major power outages. A recent study proposed installing sensors every ten miles over the existing 157,000 miles of transmission lines nationwide at a cost of $25,000 per sensor, amounting to $100,000,000 if the sensors are replaced every five years. Average residential monthly utility bills would increase by 0.004 cents per kilowatt-hour. The total cost for the proposed service would be about one tenth of the estimated annual cost of blackouts (Hammer and Parshall, forthcoming). Other components of smart grids include two-way communication systems between producers and consumer, and can include the possibility of integrating renewable energy generated by consumers into the system.

Costs for additional adaptation strategies include:

- The Energy Department expects that electricity use and production will increase by 20% over the next decade; however the nation's high-voltage electric network will only increase by 6% in the same time period. After the major blackout of 2003 many have been calling for investments ranging from $50 billion to $100 billion to reduce severe transmission bottlenecks and increase capacity (Hammer and Parshall, forthcoming).

- In some places adaptation cost incentive programs can be used to prevent power outages. Customers participating in voluntary options such as the "Distribution Load Relief" program must be reduced at least 50kW or 100kW, for individuals or aggregators respectively to receive compensation of at least $0.50 per kWh after each event (Hammer and Parshall, forthcoming).

6.5 Summary and Knowledge Gaps

- Research is needed to better understand how climate change may affect markets for gas and oil, as well as how climate change may affect the breakdown of demand for natural gas for building heat versus power generation (Hammer and Parshall, forthcoming).

- There is a need for additional research analyzing trends in a wider range of climate variables, including how seasonal and extreme trends may affect electricity demand (Hammer and Parshall, forthcoming).

- Research is also necessary to better understand how upstate utility companies will be monetarily affected by a decreased heating demand in the future (Hammer, 2010).

- An initial assessment of the relationship of a carbon tax (or cap and trade) on the energy sector is needed as a foundation for a range of policy choices, including the impacts or climate change and adaptations on the sector.

- A more extensive analysis of how substantial investments not now planned, such as making the electric grid resilient against electromagnetic storm will impact policies for climate adaptation is needed.

- Both supply and demand adaptation strategies often serve a dual role as climate change mitigation strategies, depending on the temporal scale, cost level, target audience, technology and policy decisions, and decision rules emphasized and more should be learned about these dual roles (Hammer and Parshall, forthcoming).

Technical Notes – Energy Sector
Impact: Heat-related blackouts
Adaptation: Smartgrid

Assumptions

- 2.4% GDP growth rate *(= to the long term US GDP growth rate)*
- Heat-related blackouts can also serve as a proxy for heat waves and thunderstorms.
- The baseline is based on the 30-year period from 1966 to 2006, where blackouts occurred in 1977, 1999, 2003, and 2006.
- All costs were indexed to 2006 values.
- Blackout costs based on New York City blackouts; scaled up by 1.3 to produce a state-wide estimate.
- Based on the findings by the Multihazard Mitigation Council that every $1 spent in public disaster mitigation results in a $4 savings in non-incurred disaster losses (Jacob et al., forthcoming-a).
- Based on a report finding the cost to install a $25,000 sensor every 10 miles over the existing US transmission line system that would cost $100M per year if the sensors are replaced every 5 years (Apt et al, 2004, http://www.issues.org/20.4/apt.html).
- Electricity customer and consumption information from http://www.eia.doe.gov/cneaf/electricity/esr/table5.html.

Baseline:

1. To find the baseline impact cost of blackouts in NYC, estimates of impacts were taken from available literature and studies, including Hammer and Parshall (forthcoming), to create a potential range of impact costs for each previous blackout (1977, 1999, 2003, and 2006).
    a. For the 1977 New York City-wide blackout, the ClimAID Energy chapter notes that the impact cost estimates for the blackout are roughly around $60M (low range). Another estimate from a 1978 report prepared for the Department of Energy by Systems Control Incorporated estimated the total cost of the blackout to be $290M (http://blackout.gmu.edu/archive/pdf/impact_77.pdf) (high range).
    b. To calculate the 1999 costs estimate for the heat wave that affected 170,000 Con Edison customers, the literature reported that ConEd compensated individuals $100 for spoilage of food and medicine and businesses $2,000. The low estimate assumption is that all 170,000 affected were residents while the high estimate assumes that all customers were businesses. Therefore, the total costs range from $17M to $340M.
    c. For the 2003 city-wide storm, estimates range from $125M (estimates from Hammer and Parshall [forthcoming]: $75-100M lost by restaurants, $40 in lost tax revenue, and $10M in overtime payments to city workers) to $1B (given by NYC's Comptroller William Thompson).

   d. The 2006 Queens blackout low cost estimate of $117M includes the Con Edison total claims amount, plus the estimated spending on recovery costs to repair and replace damaged equipment ($17M + $100M). The high end of the range is $188M, found in a study done by the Pace Energy and Climate Center (http://www.crainsnewyork.com/article/20100716/FREE/100719876).
2. Average the range of costs for each blackout. The averages are: $175M in 1977, $179M in 1999, $563M in 2003, and $153M in 2006.
3. Index these costs to $2006. All values were indexed using the CPI Inflation Calculator on the US BLS website: http://www.bls.gov/data/inflation_calculator.htm. The indexed averages are: $582M in 1977, $217M in 1999, $617M in 2003, and $153M in 2006.
4. Take the average of the indexed values (=$392M).
5. To calculate the annual costs, divide the average of indexed values by the number of years (30) over which these blackouts occurred (1966-2006). The annual blackout cost over a 30-year period is $13M.
6. To scale up the annual cost from New York City to New York State, multiply by 1.3 (based on the assumption that, on average, annual state-wide costs would be 30% of those for a New York City blackout). The total is $17M.
7. Project the baseline cost into the future using a 2.4% GDP. To find the total cost per blackout (for use in later calculations), multiply the annual blackout cost by 10 (based on the assumption of a 1-in-10 year blackout).

Annual incremental cost of climate change impacts, without adaptation:

8. Based on the ClimAID heat wave observations and projections, there are currently 2 heat waves per year (defined as 3 or more consecutive days with a maximum temperature exceeding 90°F). Assuming blackouts occur once in every 10 years (Wharton School 2003), it can be estimated that 1 out of every 20 heat waves results in a blackout. However, it can be assumed that the energy sector’s continued investment for general purposes (rather than specifically for climate change)—the “without” investment--will reduce this incidence, perhaps substantially, as the industry routinely operates in a warmer environment.
9. Following the climate change heat wave projections in ClimAID, the projected increase in heatwaves per year is 3 to 4 per year in the 2020s, 4 to 6 per year in the 2050s and 5 to 8 year in the 2080s. Based on this information, and if blackouts were to continue to occur once in every 20 heatwaves, then blackout occurrences would increase to 1 blackout every 6.7 to 5 years in the 2020s, 1 blackout every 5 to 3.3 years in the 2050s, and 1 blackout every 4 to 2.5 years in the 2080s. However, it would be more realistic to assume a lower incidence of blackouts/heatwaves, as noted above. Instead, for this extrapolation, it is assumed that in the 2020s blackouts will occur once in every 25 heatwaves (instead of the one in 20 now; the estimates for the 2050s and 2080s are one in every 30 heatwaves, and one in every 35. This secular improvement in system reliability is assumed to reflect constant improvements in the industry.
10. Using the total cost per blackout found in step 7, estimate projected annual blackout costs by dividing the new yearly occurrence interval into the total cost per blackout for the respective timeslice. These annual costs were then subtracted from the annual

average baseline costs without climate change for the respective timeslices . All of the costs calculated in this way, both with and without climate change, were reduced by the factors of 20/25, 20/30, and 20/35, respectively, for the 2020s, 2050s, and 2080s, reflecting the secular improvement in system efficiency.

Annual costs of adaptation:

11. The annual estimated cost to install and maintain a smart grid system in the US (with 1 sensor every 10 miles over 157,000 miles of transmission wire, where sensors cost $25,000 and need to be replaced every 5 years) is $100M per year (Apt et al, 2004). It can then be assumed that the cost to New York State is proportional to its energy consumption when compared to the national level, which is 4%. Therefore, the estimated cost of a smart grid system for New York State is $4M per year. It was assumed that this was one of 5 adaptation options of the same cost, and that 0.3 of the total was due to adaptation and the remainder to other pressures., so that adaptation costs in the first year of the example are $6.

Annual benefits of adaptation:

12. Based on the Multihazard Mitigation Council finding that "for every $1 spent in public disaster mitigation there is a savings of $4 in non-incurred disaster losses" (Jacob et al., forthcoming-b), multiply the total annual adaptation cost of $4M by 4. This results in an annual benefit of $16M.
13. Project out the annual future benefit ($16M) at a 2.4% GDP growth rate, adjusted for the 50% element that is not for climate adaptation.

Incremental costs of climate change impacts with adaptation:

Subtract the findings from step 13 from the incremental annual costs without adaptation found in step 10.

$US 2010 adjustment:

All of the figures in the example were adjusted to $US2010 using the United States Bureau of Labor Statistics CPI Inflation Calculator, http://data.bls.gov/cgi-bin/cpicalc.pl to yield the final calculations. This calculator was also used for other adjustments throughout the report.

7 Transportation

The transportation sector in New York State is an essential part of the economy and culture of the state; with its many modes and organizations, it is a complex system. There is a very large range of potential impacts of climate change on the state's transportation sector from the principal climate drivers of rising temperatures, rising sea levels, higher storm surges, changing precipitation patterns, and changes in extreme events such as floods and droughts. This analysis estimates that total impacts without adaptation could be in the hundreds of billions of dollars. Adaptations are available that would be cost-effective. Planning for these should begin as soon as possible.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR TRANSPORTATION SECTOR

Key Economic Risks and Vulnerabilities

Of the many vulnerabilities, the most economically important include first the impacts on infrastructure investment and management of rising sea levels and the accompanying increase in storm surges for coastal areas. These effects will impact all forms of transportation in coastal areas, where a large proportion of fixed investment is close to the present sea level (roads, airports, surface rail) and a significant fraction (tunnels, subways) is below sea level (Jacob et al., forthcoming–a). One of many examples of low-lying infrastructure is the Corona/Shea yards in Queens, NYC (Rosenzweig et al., 2007a). These yards are used to store subway and LIRR cars, respectively, for rush hour and other use. They flood under current conditions, and will be still more vulnerable as sea level rises. In addition to coastal flooding from sea level rise and storm surges inland flooding and urban flooding from intense storms create other important vulnerabilities in the transportation sector.

Another important vulnerability economically is increased transportation outages attributable to climate change. To the extent that extreme events increase in frequency (floods, droughts, ice storms, wind) these will impact all forms of transportation throughout New York State. The August 8, 2007 storm, for example, had severe impacts on transportation throughout the NYC area; these are detailed by mode in Metropolitan Transportation Authority (MTA) 2007. The main climate and economic sensitivities are shown in Table 7.1.

The expected impacts of climate change on transportation in New York State are very great. An example for the 100-year hurricane, based on the detailed example in Jacob et al. (forthcoming-a) and potential adaptation costs are given in Table 7.2. An increment for upstate storms is included also. In this sector, the stated storm (100-year hurricane) essentially covers all transportation for the given storm. However, this will be an understatement of damages, as many other storms will also take place, including contributions from both smaller and some greater than the 100-year storm; and from non-storm related climate factors (e.g. heat waves).

Table 7.1. Climate and Economic Sensitivity Matrix: Transportation Infrastructure Sector (Values in $2010 US.)

Element	Main Climate Variables				Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
	Temperature	Precipitation	Sea Level Rise & Storm Surge	Atmospheric CO_2			
Permanent and temporary coastal flooding from SLR and storm surge			●	●	-Damage to all modes of transportation in low-lying areas, including increased transportation outages	$100-170M for 100-year hurricane and some upstate losses	Costs: $290M Benefits: $1,160M
Inland flooding		●			-Damages to all modes of transportation in flood plains, including increased transportation outages	Substantial costs to be estimated	Improved culvert design, flood walls
Track and other fixed investment	●		●		-Potential buckling of tracks -Damage to road surfaces + Longer season for maintenance and repairs	Monitoring of climate change required	Revised design standards
Power Outages	●	●	●		-Impacts on subway and train power -Impacts on signals on highways an local streets -Impacts on airport operation	Significant economic and social impacts	Smart grid and other investment costs
Total estimated costs of key elements						$100-$170M	Costs: $290M Benefits: $1,160M

Note that the damages are annualized, although the incident is a single storm.

Key for color-coding:

(dark blue)	**Analyzed example**
(medium blue)	**From literature**
(light blue)	**Qualitative information**
(white)	**Unknown**

Table 7.2. Illustrative key impacts and adaptations: Transportation Infrastructure Sector (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)[1]	Annual incremental costs of climate change impacts, without adaptation ($M)[2]	Annual costs of adaptation ($M)[3]	Annual benefits of adaptation ($M)[4]
Outages from 100 year hurricane and upstate intense rainfall	Baseline	$520	-	-	-
	2020s	$740	$10 - $40	$140	$570
	2050s	$1510	$100 - $170	$290	$1160
	2080s	$3080	$320 - $410	$590	$2370

[1] *Based on the 100-year hurricane study in the Transportation chapter, adjusted to remove the estimated New Jersey portion of the NY Metro area, and increased by 5% to reflect upstate intense rainfall events, and annualized.*
[2] *Based on the growth of damages given in Jacob et al (forthcoming-a). between the present sea level and a SLR of 2 feet, using the range of SLR scenarios in NPCC (2010) SLR scenarios, p. 172, and scaled up for growth in damages.*
[3] *Taken as beginning in 2010 with $100m in annual investment, the low end of the range of figures given in Jacob et al. (forthcoming-a) (100s of $millions to $billions annually).*
[4] *Based on the estimate in Multihazard Mitigation Council (2005a) of a 4:1 benefit cost ratio for hazard mitigation investments (see also the references in Jacob et al. (forthcoming).*

Results

The costs of climate change are expected to be substantial in the transportation sector, with its heavy fixed capital investment, much of it at or below sea level and subject to large impacts from sea level rise and storm surges. As the example in Table 7.2 indicates, costs of impacts are expected to be very large; adaptations are available, and their benefits may be substantial. While the numbers in the example depend on the input assumptions, within a fairly wide set of assumptions the estimates will be very large. As other examples in the sector where climate change impacts are expected to be substantial, all modes of upstate transportation systems will be affected by more intense storms, inland flooding, winds and heat.

PART II. BACKGROUND

7.1 Transportation in New York State

Transportation is an essential element of New York State's economy and society. The state not only has a full complement of roads and road traffic, but also possesses, in the New York metropolitan area, the major share of the largest public transportation complex in the United States. Further, the Port of New York and New Jersey is one of the largest in the nation; there are 3 high-traffic airports in the New York City area, and many smaller commercial and private airports. There is also an extensive rail network. These systems are quite dense, most of all in the New York Metropolitan Area (see Figure 7.1 for subways and rail lines), but also in terms of the highway and rail networks of New York State as a whole. As fully described in Jacob et al. (forthcoming-a), these systems are operated by a multitude of public and private entities.

Figure 7.1. Schematic map of rail systems of the NYMA.
Source: http://www.columbia.edu/~brennan/subway/Subwaymap.gif

The transportation sector is one of those in ClimAID in which the size of the sector is reported almost exactly in the official state GDP figures issued by the U.S. Bureau of Economic Analysis. Industries are divided into North American Industry Classification System (NAICS), (U.S. Bureau of Economic Analysis, n.d.) covering Canada, the U.S. and Mexico; these replace the former Standard Industrial Classification codes used in the US. The main NAICS classification for transportation is transportation and warehousing, excluding Postal Service, and the subsidiary parts are: Air transportation; Rail Transportation; Water transportation; Truck transportation; Transit and ground passenger transportation; Pipeline transportation; and Other transportation and support activities. New York State has substantial components in each of these. For the 2008 current dollar state GDP figures, New York State GDP was $1,144,481,000,000; of this total, $19,490,000,000 was in the transportation sector. (The state figures do not break down the subcomponents.) It is also of interest that total 2008 current dollar GDP for the NY-Northern NJ-Long Island NY-NJ-Pa Metropolitan Statistical Area (MSA) was $1,264,896,000,000; the transportation sector figure is not provided to avoid disclosure of confidential information. This MSA includes 1 county in PA (Pike) and none in CT.

These figures, while of great interest in comparing current output of different sectors, are flow figures, that is, output per period of time (in this case, one year). They thus understate the immense importance of transportation to the state, which is perhaps better defined in terms of the way in which transportation activities are intertwined in nearly every action of government, businesses, and private citizens. This importance is also emphasized by the enormous capital investments in the transportation sector in New York State. As examples, Jacob et al.

(forthcoming-a) cites asset values of $10 billion for Metro North, $19 Billion for the Long Island Rail Road, and $25 billion for MTA bridges and tunnels.

7.2 Key Climate Change Sensitivities

Climate sensitivities in the transportation sector are described in detail in Jacob et al. (forthcoming-a); a comprehensive list for the nation as a whole is given in the Annexes to Chapter 5 in National Research Council (2008). Another comprehensive source is Canadian Council of Professional Engineers (2008). The most significant impacts are shown in Table 7.3:

Table 7.3. Key climate changes sensitivities: Transportation Infrastructure Sector

Rising sea levels and the associated storm surges will cause flooding of the large transportation systems in the state in coastal areas, including road, rail, aviation and maritime transport facilities.
Potentially more frequent and intense precipitation will cause inland flooding from events on roads, public transit systems and railroads, leading to more frequent outages.
Increased ice storms, especially in Central and Northern New York State, will impact all forms of transportation.
Weather-related power failures will impact all forms of transportation.
Higher temperatures and more frequent heat waves may adversely impact rail tracks and other fixed investment.

7.3 Impact costs

In estimating the costs of climate change in the transportation sector in New York State, relatively standard methods can be applied; however, data are often inadequate and the uncertainties in the climate sector are large, compounded by uncertainties in other drivers such as population and real income growth. In many cases, however, an assessment of magnitude can be obtained. Such is the result of the case study in Jacob et al. (forthcoming-a), in which a moderately strong storm's flooding impacts on the New York Metropolitan region are estimated, and then sea level rise is added to indicate the impact of climate change. The selected storm is a hurricane that would produce coastal flooding equivalent to the 100 year flood (as currently calculated). Then, sea level rises of 2 and 4 feet are added, and the flooding from the same storm is estimated. Impacts on the relevant transportation structures are calculated, and then estimates are made of the extent of transportation outages. These damages include both above-ground and below-ground systems that will require repair (Jacob et al., forthcoming-a). (In addition, hurricanes result in flooding damages to non-transportation infrastructure below street level, and much of this infrastructure is needed for a fully functioning transportation system.) Using the simplifying assumption that the overall economic impact would be a direct result of the relative functionality of the transportation systems, an estimate is made of the economic loss per day until nearly full functionality is restored. In addition to the economic losses, direct damages to physical transportation infrastructure are estimated. The results are given in Jacob et al. (forthcoming-a) Table 4, adapted here as Table

7.4, where estimates of combined economic costs and physical infrastructure damage are given for the 3 scenarios. These are given for 2010 asset values and 2010 dollar valuation.

Table 7.4. Combined Economic Production and Physical Damage Losses, in Billions, for the Metropolitan Region for a 100-year Storm Surge for three SLR Scenarios (for 2010-Assets and 2010-Dollar Valuation).

Scenario	Economic Production ($Billion)	Physical Damage ($Billion)	Total Loss ($ Billion)
S1	$48	$10	$58
S2	$57	$13	$70
S3	$68	$16	$84

S1=current sea level; S2 = S1 + 2 ft; S3=S1 + 4 ft.

Interpreting the results, the climate change costs of the impacts are the initial scenario costs subtracted from the larger future costs due to sea level rise, or $12 billion and $26 billion respectively for the chosen storm. These costs are underestimates, because asset values will rise over time; and they may be underestimates also because storm frequency and intensity may increase.

In the Jacob et al. (forthcoming-a) study, the possibility of lives being lost is acknowledged but not included. The most recent northeast hurricane that caused significant loss of life was Floyd (1999), a Category 2 hurricane. Blake et al. (2007) give the number of lives lost as 62 for that event. For the future, the possibility of deaths from hurricanes in the New York State coastal region depends on several factors. The coastal counties have well-developed evacuation plans (Jacob et al., forthcoming-a), with most residents living within a relatively short distance of higher ground. At the same time, it can be expected that hurricane tracking systems will improve continuously, so that the available time for evacuation will tend to grow over the years. However, there are some possible scenarios where there could be extensive loss of life, from wind damage as well as flooding, and this should be taken into account in adaptation planning. As a monetary measure of lives lost (not of course a full basis for decision-making), the Public Health chapter of this report gives an estimate of $7.4 million ($2006) per life.

For a full accounting of sea level rise and associated storm surge damages in the NYMA, the costs from all storms with different recurrence intervals or annual probabilities would have to be examined and the results summed, an effort that would be difficult to accomplish with current data; however, the case study shown, by indicating the magnitude of damages from a moderate storm, suggests very much higher damages if all storm probabilities and their related costs are considered. It should also be noted that one reason that impacts on transportation are high in the NYMA is that much of the fixed investment is underground, at or below sea level and is currently not well protected. It should be noted that these are the costs of impacts without adaptation measures—there will undoubtedly be adaptations that would reduce these impacts.

In summary, while there are many assumptions that go into such a calculation, the overall level of magnitude indicates that losses from climate change in the NYMA from SLR and storm surge will be substantial without suitable adaptation. These costs, without adaptation, for the transportation sector could be in the hundreds of $billions. The reductions in such costs that are attributable to adaptation measures constitute the benefits of the adaptations. Many available adaptations to climate change in this sector will be both worthwhile and essential. These will have to be planned and implemented in a carefully staged manner to stay ahead of the worst of the impacts.

7.4 Adaptation Costs

There is a wide range of potential adaptations to the impacts of climate change on transportation systems; these can be divided into adaptations for: management and operations; infrastructure investment; and policy. Adaptations can also be classified as short-, medium- and long-term; examples of these are in Jacob et al. (forthcoming-a). Costs vary substantially among different types of adaptations; and the adaptations need to be staged, and integrated with the capital replacement and rehabilitation cycles (Major and O'Grady, 2010). There has begun to be a substantial number of studies about how to estimate the costs of adaptations, and in some cases, cost estimates (Parry et al. 2009; Agrawala, and Fankhauser, eds., 2008).

Among adaptations for New York State transportation systems will be changes to cope with rising sea levels and the accompanying higher storm surges, and climate-related transportation and power outages throughout New York State. While costs for adaptations, as opposed to discussions of methods, are not widely available as yet, some sense of the magnitude can be obtained by considering available information on hazard reduction. The Multihazard Mitigation Study (2005b) examined the benefits and costs of FEMA Hazard Mitigation grants, including one set of grants to raise streets in Freeport, NY (pp. 63-64 and 107) to prevent flooding under existing conditions. (A companion effort to raise buildings is described in the OCZ chapter.) These totaled about $2.76 million, including a 25% local matching contribution. The study examined a wide range of parameter values of benefits and costs, and concluded that the total Freeport benefit-cost ratio best estimate was 2.4; the range is shown Table 7.5. This provides some sense of what might be required in the future in coastal areas such as Freeport, which of course do not have underground transit lines as does the inner core of the NYMA.

Table 7.5. Benefit Cost Analysis of Potential Climate Change Adaptation: Raising Local Streets Subject to Flooding

Activity in Freeport, NY	Total Costs (2002 $M)	FEMA Costs (2002 $m)	Best Estimate Benefits (2002 $M)	Best Estimate Benefit-Cost Ratio	BCR Range
Street grading/elevation	$2.76	$2.07	$6.52	2.4	0.19-9.6

Source: adapted from: Multihazard Mitigation Council, 2005b, vol. 2, p.107,Table 5-14.

An example of larger costs for adaptation of transportation systems comes from Louisiana, which is in the process of upgrading and elevating portions of Louisiana Highway 1, which in its current configuration floods even in low-level storms. The project has several phases and includes a four-lane elevated highway between Golden Meadow, Leeville, and Fourchon to be elevated above the 500-year flood level and a bridge at Leeville with 22.3-m (73-ft) clearance over Bayou LaFourche and Boudreaux Canal. Construction has begun on both the bridge project and a segment of the road south of Leeville to Port Fourchon. The bridge project has a value of $161 million, and while this might be taken as an adaptation to current conditions and risks rather than climate change, it is indicative of the level of costs for large infrastructure projects subject to coastal storms, the impact of which will increase substantially with rising sea levels. (Savonis et al., 2008, p. 4-55).

A second example of estimating the costs of actual design for climate change adaptation of a transportation project is in Asian Development Bank (2005). This case study examined a road building development plan for Kosrae in the Federated States of Micronesia, specifically a 9.8-km unbuilt portion of the circumferential road north of the Yela Valley. This route is subject to flooding; the specific design climate driver was chosen in this case is the hourly rainfall estimated with a 25 year return interval. This was forecast to rise from 190 mm to 254 mm in 2050. There is a detailed climate-proofed design plan for the road design, including construction, maintenance and repair costs for the built and unbuilt sections of the road. The estimated marginal cost for climate-proofing is $500,000; the study further concludes that would be more costly to climate proof retroactively. As of the report date, the Kosrae state government decided not to proceed with construction of the road until additional funds were available for climate proofing. This example, although in a tropical area with higher rainfall than New York State, presents a typical problem in road design that is relevant to the state—adaptation of designs to more intense rainfall.

A pioneering large infrastructure decision actually made on the basis of adaptation to sea level rise is in Canada: "…the designers of the new causeway to Prince Edward Island made it one meter higher than it would otherwise have been" (Titus, 2002, p. 141). This structure, completed in 1996, is called the Confederation Bridge. Because the adaptation to sea level rise was included in the initial designs, the marginal cost of the adaptation was not estimated. (This might, however, be possible with a detailed examination of the design documents.)

A very large-scale adaptation relevant to the reduction of climate change impacts on transportation is a set of surge barriers for New York Harbor; these are described in the OCZ chapter. However, such a regional solution needs a thorough analysis of its long-term sustainability for the scenarios under which sea level rise continues beyond the height and useful lifetime of such barriers (say, for example, 100 years)--an exit strategy. Benefit-to-cost ratios can change with time, and the question arises what is the proper time horizon for making decisions, and how can adaptation (and its cost) be adjusted to uncertain future long-term conditions of climate, economics and demographics.

For still other adaptations, on a much shorter time scale, costs have not yet been estimated but could be estimated from existing information and reasonable forecasts. For example, the New York State Department of Transportation has a 24/7 emergency command center in Albany to deal with road blockages and outages from extreme events. The NYSDOT is able to move resources among its divisions fairly quickly because of this information center. If extreme events increase due to climate change, it would be expected that the budget for this operation and the associated costs of resource movement would increase gradually over time; these budget increases would be costs of adaptation.

7.5 Summary and Knowledge Gaps

From the standpoint of improving the ability of planners to do economic analysis of the costs of impacts and adaptations in the transportation sector, there are many knowledge gaps to which resources can be directed. These include:

- A comprehensive data set in GIS or CAD form of as-located elevations of transportation infrastructure relative to current and future storm surge inundation zones and elevations.
- Increased staffing of planning and risk management units in transportation agencies
- Updating of FEMA and other flood maps to reflect the impacts of rising sea levels.
- Undertaking of a series of comprehensive benefit-cost analysis of potential adaptations to aid in long term planning.
- Integration of population projections into climate change planning.
- More advanced planning for power outages and their impacts on transportation.
- Forecasts of improvements in information technology, such as hurricane models, which should be able to provide improved real-time forecasts to enable more efficient evacuation planning.

Technical Notes – Transportation Infrastructure Sector

Methods for estimating transportation impact and adaptation costs for 100-year hurricane:

1. This extrapolation is based on the transportation case study in Jacob et al. (forthcoming-a).

2. The total loss for the baseline is $58 billion for the reference study, or $.580 billion annually.

3. This is for the NY Metro area. This includes 1 county in PA (Pike), 10 in NJ, and none in CT.

4. The total loss was reduced by 15% to exclude the transportation-related losses for NJ, and was then increased by 5% to include transportation related intense rainfall outages in New York State. This yields $.520 billion annually. The growth in annual costs was projected with the long term US GDP growth rate of 2.4%. This was used because the example in the transportation chapter is for current asset values.

5. Then, the incremental losses were estimated by using the range of SLR in inches for benchmark years, times the increased loss per inch. The increased loss per inch is $.5 billion, taken linearly from the increase of 12 billion for an increase of 24 inches. The annualized incremental loss is 5 million.

6. Adaptation costs were reduced by judgment to the low end of the ranges given in the ClimAID Transportation chapter, which go upward into the billions of dollars per year. The lower range was chosen because the ClimAID figures include not only adaptations to future climate but also needed infrastructure spending for general purposes.

7. Benefits (reduction in costs) were based on empirically derived 4:1 figure in the Transportation chapter. Because so many important adaptations have not been made, annual benefits may be higher than the conservative estimate used here.

8 Telecommunications

The capacity and reliability of New York State's communication infrastructure are essential to its economy and consequently to the effective functioning of global commerce (Jacob et al., forthcoming-b). The communications sector includes point-to-point switched phone (voice) services; networked computer (Internet services, with information flow guided by software-controlled protocols; designated broadband data services; cable TV; satellite TV; wireless phone services; wireless broadcasting (radio, TV); and public wireless communication (e.g. government, first responders, special data transmissions) on reserved radio frequency bands (Jacob et al., forthcoming-b). The sector poses special challenges to climate change analysis. Businesses in the sector are reluctant to disclose some classes of information that would be relevant to climate change assessments, due to competitive pressures and also concerns about potential additional regulation (Jacob et al., forthcoming-b). Thus, as compared to some other ClimAID sectors, it is relatively difficult to quantify the costs of climate change impacts on capacity and reliability and adaptation strategies to protect these assets. Adaptation costs can be minimized if adaptations to climate change are incorporated into the existing short-term planning schedule. Adaptation costs could then become standard equipment update/upgrade costs rather than additional replacement costs.

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR TELECOMMUNICATIONS SECTOR

Key Economic Risks and Vulnerabilities

By affecting systems operations and equipment lifespan, more intense precipitation events, hurricanes, icing and lightning strikes, and higher ambient air temperatures (Connecticut Climate Change Infrastructure Workgroup of the Adaptation Subcommittee, 2010) will impact the capacity and reliability of the communications infrastructure sector. Table 8.1 identifies the climate variables that are likely to impact the sector along with the project economic outcome. Note that economic risks significantly outweigh opportunities. Furthermore, this sector integrates and overlaps with each of the other sectors and impacts in the communication sector will likely have secondary or tertiary effects throughout the economy.

Table 8.1. Climate and Economic Sensitivity Matrix: Telecommunications Sector (Values in $2010 US.)

Elements	Main Climate Variables: Extreme Events: Heat	Main Climate Variables: Extreme Events: Ice and Snow Storms	Main Climate Variables: Extreme Events: Hurricanes, Rain, Wind & Thunderstorms	Main Climate Variables: Electric Power Blackout	Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs and benefits of climate change at mid-century
Equipment Damage System Failure	●	●	●	●	– Damaged power and communication lines and poles – Infrastructure damage – Unmet peak energy demands (i.e. for AC) will cause power outages and incidentally communication outages	$15-30M	Costs: $12M Benefits: $47M
Total estimated costs of key elements						$15-30M	Costs: $12M Benefits: $47M

Key for Color-Coding:

(dark blue)	**Analyzed example**
(medium blue)	**Analogous number or order of magnitude**
(light blue)	**Qualitative information**
(white)	**Unknown**

Winter storms can result in outages in communications systems, a key concern for the sector relating to climate change. Past storms have resulted in communications outages, which have translated to several million dollars of lost revenue and damage. One advantage in the communications sector is that, due to the frequently updated technology, the equipment is often replaced on a short time cycle. This allows for the opportunity to include climate change into the new design or life-cycle replacement of equipment. However, because the costs of a communication outage can be so significant, it is still important to consider the investment of adaptations to minimize the impacts from climate change. Table 8.2, below, illustrates the estimation of costs from a communication outage due to a severe winter storm and the benefits that two different types of backup systems could bring. For complete methodology, see technical note at the end of this chapter.

Table 8.2. Illustrative key impacts and adaptations (Values in $2010 US.)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)[1]	Annual incremental costs of climate change impacts, without adaptation ($M)[2]	Annual costs of adaptation ($M)[3]	Annual benefits of adaptation ($M)[4]
Outages from a 1-in-50 yr storm[1, 2]	Baseline	$40	-	-	-
	2020s	$72	$7 - $14[3]	$6	$23[5,6]
	2050s	$147	$15 - $30[3]	$12	$47[5,6]
	2080s	$300	$30 - $60[3]	$24	$95[5,6]

[1] *From the case study in Jacob et al , forthcoming-b), "Communications outage from a 1-in-50 year winter storm in Central, Western and Northern New York"*

[2] *The values presented are based on a growth rate for GDP of 2.4%.*

[3] *Based on the findings by the Multi-hazard Mitigation Council that every $1 spent in public disaster mitigation results in a $4 savings in non-incurred disaster losses (Jacob et al., forthcoming-a).*

[4] *Future changes in winter storms are highly uncertain, however, because it is more likely than not that severe coastal storms will become more frequent, 10% and 20% increases in storm damage are estimated here to serve as a sensitivity test, but should be used for illustrative purposes only.*

[5] *Based on the findings that it would cost $10 million to develop a rooftop wireless backup network in lower Manhattan (Department of Information Technology and Telecommunications, & Department of Small Business Services [NYCEDC, DoITT, & DSBS] 2005, p.37) and the assumption that this network would have a 10-year lifespan. Additionally, it is assumed that annual NYC-wide costs for a wireless backup network system would be 3 times the costs of Lower Manhattan (based on the 2 other concentrated building locations in midtown Manhattan and downtown Brooklyn).*

[6] *Based on the annual estimated costs for fiber optic network from Jacob et al. (forthcoming-b) and the assumption that this network would have a 40-year lifespan. The fiber optic network was not scaled down to include NYC based on the assumption that there is already a fiber optic network in place there.*

Results

Based on the economic impact estimate of $2 billion from the ClimAID Telecommunications chapter of the damage and lost revenue from a severe winter storm, calculations were made taking into consideration the potential future impacts that may result from climate change. The baseline costs can be estimated to increase at the rate of GDP growth in the future. Based on an estimate of a 2.4 % GDP growth rate, the annual costs from a communications outage without climate change were estimated to between $72 million in the 2020s, $147 million in the 2050s and $300 million by the 2080s. Since the climate information regarding changes in winter storms is not certain enough to give a precise predication regarding the increased frequency of winter storms in the future, an estimate of a 10% increase and 20% in these types of storms during each time period was used to serve as a sensitivity test. In this case, the incremental annual cost of a communications outage above the baseline was estimated to be $7 to $14 million for the 2020s, $15 to $30 million for the 2050s, and $30 to 60 million for the 2080s.

In order to reduce the impacts of climate on the communications sector, there are a number of adaptation options. The two illustrative examples chosen in this case study were the development of a rooftop wireless backup network for New York City with a lifespan of 10 years and the development of a fiber optic network for upstate with a lifespan of 40 years. These two examples were selected because they are feasible with current technology. If these kinds of adaptations were put in place, the result would be annual incremental benefits through the end of the century of $33 million for the 2020s, $40 for the 2050s, and $98 for the 2080s. The annual benefits of adaptation can then be calculated to be $25 million for the 2020s, $61 for the 2050s and $147 for the 2080s. These costs can be compared to the annual costs of adaptation for these systems of $4 million.

PART II. BACKGROUND

8.1 Telecommunication Infrastructure in New York State

Because communications infrastructure is replaced on approximately a 10-year cycle, adaptation to climate change can be more of an ongoing, integrated process in this sector than in sectors with longer-lasting infrastructure.

State GDP and Employment

The size of the Communications sector is roughly reported in the official state GDP figures issued by the U.S. Bureau of Economic Analysis. The NAICS classification for Communications is Broadcast and Telecommunications. For the 2007 (2008 n/a) current dollar state GDP figures, New York State GDP was $1.144 trillion; of this total, $43.763 billion was in the Broadcast and Telecommunications sector. This NAICS includes a wider range of industries than are discussed in the telecommunications sector included in ClimAID. The total annual revenue for telecommunications is $20 billion, contributing approximately 2% of the $1.1 trillion gross state product (GSP) (Jacob et al., forthcoming-b).

More than 43,000 people are employed by telecommunications, cable, and Internet service companies in New York City, earning an average salary of $79,600. In 2003, these telecommunications, cable, and internet service companies produced a combined output of over $23 billion, totaling more than three percent of the city's economy (New York City Economic Development Corporation, Department of Information Technology and Telecommunications, & Department of Small Business Services [NYCEDC, DoITT, & DSBS], 2005, p. 9).

8.2 Key Climate Change Sensitivities

Communications in New York State are interconnected, overlapping, and networked, and boundaries are constantly in flux (Jacob et al., forthcoming-b). Due to network complexity, communications infrastructure is vulnerable to many different failure modes. The primary cause of failure for communication networks is commercial grid and service provider back-up power failures due to communications interdependence with power (Jacob et al., forthcoming-b). This section identifies the facets of climate change that will cause broadcast, telecommunication, and power outages and thereby affect the key economic components of the sector.

Table 8.3. Climate Change Sensitivities: Telecommunications Sector

Ice storms will damage power and telecommunication lines and poles. In December 2008, federal disaster aid totaled more than $2 million for nine New York counties that suffered damage from an ice storm.
Hurricanes. A slight increase in the intensity of hurricanes or storm surges will likely cause a substantial increase in infrastructure damage (Stern, (2007) Communications in coastal areas will be vulnerable to coastal flooding intensified by sea level rise.
Rain, wind, and thunderstorms will damage power and telecommunication lines and poles. Riverine and inland flooding caused by intense precipitation will also threaten low-lying Communications.
Heat. Unmet peak energy demands for air conditioning will cause power outages. This will indirectly lead to communication outages.
Snowstorms will damage power and telecommunication lines and poles.
Electric power blackouts. Power outages are often weather related and are a leading cause for communication outages. Risks are becoming increasingly significant as the proportion electric grid disturbances caused by weather related phenomena has more than tripled from about 20% in the 1990s to about 65% more recently.

8.4 Impact Costs

The costs of climate change impacts in the communications infrastructure sector are incurred through direct damage of equipment and productivity losses (Jacob et al., forthcoming-b). Telecommunication companies generally consider the economic data that is relevant to the ClimAID study as proprietary information. This, coupled with the limited and often voluntary requirements for communications operators to report service outages to the New York Public Service Commission (Jacob et al., forthcoming-b), combined with the fact that some of this information is not publicly accessible, makes it nearly impossible to determine the total costs of climate impacts on infrastructure. This section presents the available costs of climate change impacts for New York State.

Loss Estimates

Damage costs are fairly straightforward and include things such as the replacement of downed poles and wires, etc.

Ice and Snow Storms. The ClimAID communications case study found that the total estimated cost of a major winter storm in NY is nearly $2 billion dollars, of which nearly $900 million comprises productivity losses (due to service interruption) and $900 million comprises direct damage (spoiled food, damaged orchards, replacement of downed poles and electric and phone/cable wires, medical costs, emergency shelter costs etc.) To estimate damage and economic productivity losses, the case study used the number of people affected and the number of customers restored per number of days until restoration. It also used New York State's average-per-person contribution to the state's gross domestic product ($1.445 trillion per year per 19.55 million people equals about $58,600 per person per year, which is equal to $160.50 per person per day). Losses to the state's economy were approximated at about $600 million in the first 10 days, $240 million between days 10 and 20, and $60 million in the remaining time from days 20 to 35. In total, this amounts to about $900 million ($0.9 billion) from productivity losses alone (Jacob et al., forthcoming-b, Economic Impacts of a Blackout Case Study).

Federal aid for New York State ice storms: During an April 3-4, 2003 ice storm affecting western New York State, 10,800 telecommunications outages were reported. It took 15 days from the beginning of the storm to return conditions to normal. More than $15 million in federal aid was provided to help in the recovery (Jacob et al., forthcoming-b).

Federal disaster aid topped $2 million for the nine New York counties that suffered damages from the December 2008 ice storm. The aid for these counties and to the State of New York was (Jacob et al., forthcoming-b):

- Albany County - $295,675
- Columbia County - $123,745
- Delaware County - $324,199
- Greene County - $203,941
- Rensselaer County - $203,079
- Saratoga County - $166,134
- Schenectady County - $300,599
- Schoharie County - $324,569
- Washington County - $173,393
- State of New York - $ 10,070

Additional impact costs of ice storm events outside New York State include:

- Between 1949 to 2000, freezing rain caused more than $16.3 billion in total property losses in the United States (Changnon 2003; Jacob et al., forthcoming-b).

- The estimated cost of the 1998 ice storm that hit Northeastern US and Canada caused damages in Canada alone totaling (U.S.) $5.4 billion. In Quebec, telephone service was cut off to more than 158,500 customers. Several thousand kilometers of power lines and telephone cables were rendered useless; more than 1,000 electric high-voltage transmission towers, of which 130 were major structures worth $100,000 each, were toppled; and more than 30,000 wooden utility poles, valued at $3,000 each, were brought down. 28 people died in Canada, many from hypothermia, and 945 people were injured (Environment Canada). More than 4 million people in Ontario, Quebec and New Brunswick lost power. About 600,000 people had to leave their homes. By June 1998, about 600,000 insurance claims were filed totaling more than $1 billion (Jacob et al., forthcoming-b).

Productivity loss is slightly more complicated but can be estimated in terms of potential business that would have been done under normal circumstances. For example, the *New York Clearing House* processes up to 26 million transactions per day for an average value of $1.5 trillion (NYCEDC, DoITT, & DSBS, 2005); if the communications infrastructure is down then this business productivity loss is an impact cost of climate change.

8.4 Adaptation Costs

There are two types of adaptations in infrastructure: (1) modifications in the operations of infrastructure that is directly affected by climate change, and (2) changes in infrastructure needed to support activities that cope with climate sensitive resources (UNFCCC, 2007, p. 121). This section deals with the latter and presents the costs of climate change adaptation strategies for communications infrastructure in New York State.

Rapid changes in technology and intra-industry competition drive the constantly evolving communications sector, allowing for a planning horizon of only 10 to 20 years. Therefore adaptation to climate change will not bear significant costs if it is incorporated into the existing communications plans. It has been determined that for every $1 spent in public disaster mitigation there is a savings of $4 in non-incurred disaster losses (Jacob et al., forthcoming-b). Following this reasoning, proactively modifying communications infrastructure to adapt to climate change will benefit the sector.

Proposed adaptations to ensure a higher level of reliability in the sector include the following (Jacob et al., forthcoming-b):

- Move wired communications from overhead poles to buried facilities
- Emergency power generators and strategies for refueling generators
- Standardization of power systems for consumer communication devices
- Diversification of communication media
- Natural competition between wired and wireless networks
- Develop alternate technologies (free space optics, power line communications, etc.)

Costs are available for several specific adaptations proposed in NYC's telecommunications Action Plan:

- It will cost an average of $250,000 per building in lower Manhattan to bolster resiliency by having (1) two or more physically separate telecommunication cable entrances, (2) carrier-neutral dual risers within buildings, and (3) rooftop wireless backup systems (NYCEDC, DoITT, & DSBS, 2005, p. 33).

- It will cost approximately $10 million to develop a rooftop wireless backup network in lower Manhattan to ensure that the building's tenants could move data in the event that landline communications are disrupted (NYCEDC, DoITT, & DSBS, 2005, p. 37).

Some additional examples of adaptation costs in NY include:

- Recently, the federal National Telecommunications and Information Administration awarded a $40-million grant for the ION Upstate New York Rural Initiative to deploy a 1,300-mile fiber optic network in upstate regions as part of the federal government's broadband stimulus program (Jacob et al., forthcoming-b).

Initial analysis determined that 62 percent of telephone central offices in New York State have geographic diversity (the ability to transmit/receive signals from one location to another via two distinct and separate cable routes), while 38 percent of do not. Company estimates determined that the cost to provide geographic diversity to all remaining offices was approximately $174 million. The Public Service Commission performed a critical-needs analysis, which concluded that 40 percent of the non-diverse central offices could be equipped with geographic route diversity at a significantly lower total cost of about $13.3 million. Following this recommendation, 77 percent of central offices have now achieved geographic route diversity, covering 98 percent of the total lines in New York. This enhanced route diversity of outside cable facilities substantially increases access to emergency services, overall network reliability and the resiliency of telephone service during emergency situations.

8.5. Summary and Knowledge Gaps

From the standpoint of improving the ability of planners to do economic analysis of the costs of climate change impacts and adaptations in the communications sector, there are many knowledge gaps to which resources can be directed. These include:

- There is a need for comprehensive data bases showing the locations and elevation of installed communications facilities as well as other details. These data bases will have to be secure, but accessible to qualified researchers.
- From locational data as above, assessment need to be completed of vulnerability of infrastructure components to coastal and inland flooding.
- Within the monitoring systems that should be developed for climate analysis, wind records in relation to communications systems should be included.
- As climate changes, the important of public access to outage information will increase.
- Public health aspects of communications infrastructure should continue to be monitored.

Technical Notes – Telecommunications Sector

Impact: Communications outage from a 1-in-50 year winter storm

Adaptations: Develop a wireless backup network in New York City and construct a fiber optic broadband network in Upstate New York

Annual costs of current and future climate hazards without climate change:

1. Annualize the total storm cost given by ClimAID Telecommunications Chapter 10 based on the 1-in-50 year storm ($2,000M/50=$40M).
2. Project out annualized $40M baseline cost to 2100 accounting for the 2.4% growth in GDP (Baseline: $40M, 2020s: $72M, 2050s: $147M, 2080s: $300M).

Annual incremental costs of climate change impacts without adaptation:

3. Assume a 10% and 20% increase in baseline costs associated with an increase in storm frequency due to climate change.

Annual costs of Adaptation:

4. Estimate from the annual cost for a rooftop wireless backup network assuming 10-year lifespan ($10M/10 = $1M). Multiply this cost by 3 to scale up to the city level (representing two other concentrated areas in the city, Midtown Manhattan and Downtown Brooklyn).
5. Estimate the annual cost for fiber optic network assuming 40-year lifespan ($40M/40 = is $1M).
6. Add the totals from steps 4 and 5 for a total annual adaptation cost of $4M.
7. Projected out the costs of adaptation ($4M) to 2080 based on 2.4% GDP growth (2020s: $6M; 2050s: $12M; 2080s: $24M)

Annual benefits of adaptation:

8. Based on the Multi-hazard Mitigation Council finding that "for every $1 spent in public disaster mitigation there is a savings of $4 in non-incurred disaster losses" (Multihazard Mitigation Council 2005a; Jacob et al., forthcoming-a), take the annual adaptation cost of $4M and multiply it by 4 to find the savings in non-incurred disaster losses (=$16M).
9. Projected out the savings from adaptation ($16M) to 2100 based on 2.4% GDP growth are as follows: 2020s: $23M; 2050s: $47M; 2080s: $95M

9 Public Health

Climate change is anticipated to have widespread and diverse impacts on public health. On the whole these impacts will be negative, with the exception of a potential reduction in cold-related health outcomes (Parry et al, 2009, p.108). Maintenance of public health is critically linked with other sectors, particularly water resources and energy. In many cases, adaptation to climate change within other sectors is as important as the enhancement of conventional public health programs for reducing the health impacts of climate change. Appropriate adaptation in these other sectors will insure that the public health costs of climate change will be manageable (Kinney, 2010). Taking steps to prepare for climate related hazard events, to maintain grid reliability during heat waves, to secure food and water supplies, and to implement infrastructure improvements will significantly reduce the impacts of climate change on public health (Parry et al, 2009, p.52).

PART I. KEY ECONOMIC RISKS AND VULNERABILITIES AND BENEFIT-COST ANALYSIS FOR PUBLIC HEALTH

Key Economic Risks and Vulnerabilities

This section identifies climate-related changes that will have significant potential costs for the public health sector. Table 9.1 identifies the climate variables that are likely to impact some of the key facets of the public health sector with the projected economic impact by mid-century. Based on existing data, it is possible to develop rough, provisional estimates of the direct climate-change related costs for some facets of the public health sector, including costs associated with loss of life due to extreme heat and hospitalizations due to asthma. For other types of impacts including the potential costs associated with emergent, vector-borne diseases and water-borne illnesses, costs are currently unknown. The mid-century estimate of total impact costs of between roughly $3 and $6 billion dollars is an estimate of some of the critical, potential costs associated with mortality and hospitalization as the result of climate change (without adaptation). Other types of impacts may amount to several hundred million or more per year in additional costs.

Many climate change related threats to public health can be substantially reduced or even eliminated with preventative measures and adaptations such as heat wave warning programs, asthma awareness and treatment programs, and development of new vaccines for emergent vector-borne diseases. Other impacts can be reduced via appropriate adaptations action within other sectors such as maintenance of water quality to protect residents from water-borne illness. Table 9.1 provides mid-century estimates of costs associated with heat warning systems and asthma prevention programs, and also describes qualitatively a number of other types of potential adaptation costs that may be incurred with climate change.

Table 9.1. Climate and Economic Sensitivity Matrix: Public Health Sector (Values in $2010 US)

Element	Main Climate Variables: Temperature	Main Climate Variables: Precipitation	Main Climate Variables: Extreme Events: Heat	Main Climate Variables: Sea Level Rise & Storm Surge	Economic risks and opportunities: – is Risk + is Opportunity	Annual incremental impact costs of climate change at mid-century, without adaptation	Annual incremental adaptation costs of climate change at mid-century
Temperature related deaths	●		●		+ Fewer cold related deaths – More heat related deaths – Loss of life and productivity – Hospitalization costs	$ 2,988M-$6,040M (value of loss of life from heat-related deaths using VSL of $7.4M ($2006, indexed to $2010)	Costs: $ .6M heat wave warning system; Benefits: $1,636M
Air quality and respiratory health	●	●	●		– Extension of pollen and mold seasons – More suitable environment for dust mites and cockroaches – Increased ozone concentrations, due in part to higher emission of VOCs – Peak in AC use, potentially leading to loss of electricity – Change in the dispersion of pollutants in the atmosphere	$10M – $58M additional asthma hospitalization costs	Costs: $5M asthma prevention Benefits: $8M
Water supply and food production	●	●		●	– Water quality – Safety of food supply – Higher food prices + Longer growing season for local crops	Increase in water and food-borne illness; malnutrition	Increased water treatment and protection of food supply
Storms and flooding		●		●	– Loss of life from large storm event (e.g., hurricane) – Mental health issues caused by displacement and family separation, violence, or stress – Increased runoff from brownfields and industrial contaminated sites – Flooding favors indoor molds that can proliferate and release spores	Costs associated with loss of life, treatment of post-traumatic stress, and treatment of mold-related illnesses	Expansion of emergency preparedness
Vector borne and infectious disease	●	●		●	– Increased population and biting rate of mosquitoes and ticks – Greater rates of overwinter survival of immature mosquitoes	Doctor or hospital costs for treatment	Mosquitoes spraying, vaccination
Total estimated costs of key elements						$2,998 - $6,098M	Costs $6M: Benefits: $1,644M

Key for color-coding:

(dark blue)	**Analyzed example**
(medium blue)	**Analogous number or order of magnitude**
(light blue)	**Qualitative information**
(white)	**Unknown**

Table 9.2 provides more detailed estimates of the costs of climate change impacts associated with temperature-related deaths in New York City and asthma hospitalizations in New York State. Every year, several hundred deaths within New York City can be attributed to temperature-related causes, both from extreme heat and extreme cold. With a changing climate, heat-related deaths may increase due to more frequent heat waves and more days with extreme hot temperatures. A reduction in extreme cold days may mean a decrease in the number of deaths from cold. Extreme heat can also exacerbate other health problems such as cardiovascular disease and asthma, and individuals with these conditions are particularly vulnerable to heat-related illness (Kinney et al. 2008). Elderly populations and those with pre-existing health conditions are especially at risk. The number of state residents at risk for temperature-related illness is likely to increase in the future with an aging population.

Asthma is a major public health issue within New York State. Between 2005 and 2007, approximately 39,000 state residents were hospitalized annually due to asthma-related illness (New York State Department of Health [NYSDOH 2009]). In 2007, the total annual cost of these hospitalizations was approximately $535 million (NYSDOH 2009). Climate change may lead to an increase in asthma hospitalizations in New York State as the result of an increase in the frequency of high ozone days. Concentrations of ambient ozone are expected to increase in urbanized areas of the state as the climate changes due to both higher daily temperatures and increases in precursor emissions (Kinney et al. 2000; Kinney 2008; Knowlton et al., 2004, Bell et al. 2007).

Table 9.2. Illustrative key impacts and adaptations: Public Health Sector (Values in $2010 US)

Element	Timeslice	Annual costs of current and future climate hazards without climate change ($M)	Annual incremental costs of climate change impacts, without adaptation ($M)	Annual costs of adaptation ($M)	Annual benefits of adaptation ($M)
Heat-related deaths	Baseline 2050s	307 307	- 147 to 292	- NA	- 79[5]
Heat-related deaths – VSL ($7.4 M)[1, 2]	Baseline 2050s	$2,462 $6,358	- $2,988 - $6,040	- $ .622[4]	- $1,636
Cold-related deaths	Baseline 2050s	102 102	- -40 to -45	- NA NA	- NA NA
Cold-related deaths – VSL ($7.4M)[1, 2]	Baseline 2050s	$ 818 $2,112	- $-1,174 to $-1,291	- NA	- NA
Asthma (ozone)[3]	Baseline 2020s 2050s 2080s	$620 $786 $1,601 $3,262	- $2 to $11 $10 to $58 $32 to $193	- $3[6] $5 $11	- $2[7] $8 $27
TOTAL –	Baseline 2050s	$3,900 $10,071	- $1,824 to $4,807	- $ 6	- $1,644

[1] Heat and cold baseline mortality projections from Kalkstein and Greene (1997). Climate change heat projections based on Knowlton et al. 2007. Climate change cold projections based on Kinney et al. (2010). Climate change scenario projections are only available for 2050 from Knowlton et al. (2007).

[2] Based on a 2.4% GDP growth rate (BEA) and using a VSL of $7.4 million (in 2006 $), as prescribed by the U.S. Department of Environmental Protection (USEPA) (USEPA 2010, 2000).

[3]Asthma hospitalization projections are based on Bell et al. (2007) of the impacts of climate change on asthma hospitalizations as the result of ambient ozone in U.S. cities.

[4] Estimates based on average number of lives saved and average costs to run the PWWS. Actual values vary from year-to-year.

[5] Calculated based on the findings of Ebi, et al.'s (2004) study of the Philadelphia Hot Weather – Health Watch/Warming System (PWWS) , which estimated the system saved 117 lives between 1995 and 1998

[6] Estimates based on annual costs to run New York State Health Neighborhoods program.

[7] Calculated based on the study of Lin et al. (2004), which found that the New York State Healthy Neighborhoods Program lead to a 24% decrease in asthma hospitalizations in eight participating counties between 1997 and 1999.

Results

Results of the temperature and asthma analyses suggest that climate change may have substantial public health costs for New York State. New York State already incurs significant economic costs as the result of both extreme heat and extreme cold. Kalkstein and Greene (1997) estimate that there are presently 307 heat-related deaths and 102 cold-related deaths on an annual basis in New York City. We estimate the annual costs associated with temperature-related deaths in New York City using a standard VSL of $7.4 million (in $2006), as recommended by U.S. Department of Environmental Protection (USEPA) (USEPA 2010, 2000).

Even without climate change the costs of heat-related deaths in the state are substantial, approaching $2.5 billion annually. With climate change, the annual number of heat-related deaths could increase between 47 and 95 percent by the 2050s (Knowlton et al. 2007). These estimates are based on Knowlton et al.'s (2007) forecasts of increases in summer heat related deaths in the New York region under both low (B2) and high (A2) emissions scenarios. These additional temperature related deaths due to climate represent estimates of the number of lives that may be lost without appropriate adaptation. By contrast, cold related deaths are expected to decrease in New York State with climate change (Kinney et al. 2010). However, as illustrated in Table 9.2, the costs of heat-related mortality far outweigh the benefit of decreased cold-related mortality.

Heat-related deaths in the state could be considerably reduced with adaptation. Adaptation will also likely occur through expanded use of air conditioning in homes, schools and offices. Air conditioning prevalence in private dwellings has increased steadily in recent decades, and this trend is likely to continue. However, affordability of the units and energy costs continues to be a major concern. New York City has initiated a program to provide free air conditioners to elderly residents who are unable to afford them. This program cost approximately $1.2 million for each year 2008 and 2009, and entailed distribution of approximately 3000 air conditioning units to residents over 60 years old (Sheffield, 2010). Substantial expansion of this type of program may be needed to foster adaptation to climate change, given the high number of at-risk seniors not only in New York City but throughout the state. Other on-going efforts to reduce heat related mortality in New York include development of a network of cooling centers to help residents cope with extreme heat. The capital, energy and pollution-related costs of air conditioning should be borne in mind.

In the example above, implementation of a heat wave warming system, similar to the one put into place in Philadelphia (see Ebi et al. 2004) would save an average of 79 lives per year and thus lower the annual incremental costs of temperature-related deaths by $1,636 million in the 2050s, assuming a VSL of $7.4 million (USEPA 2000, 2010). Based on data from the Philadelphia study (Ebi et al 2004) such a program is estimated to cost less than $1 million annually to establish and run. Even if such a program saved only one life, the benefits would exceed the costs.

Asthma-related hospitalizations may also be affected by climate change, due largely to increases in ozone concentrations absent more aggressive emissions controls of ozone precursors (Kinney 2008). The costs associated with such hospitalizations are estimated to exceed $600 million today. Without climate change, these costs will increase over the next century, approaching $3.2 billion by the 2080s. Climate change is expected to increase the number of asthma related hospitalizations due to increased levels of ambient ozone and an increase in the severity and length of the pollen season. The above analysis estimates costs associated with increased ozone-related hospitalizations in the state under climate change based on Bell et al. (2007). Results suggest that climate change will lead to additional annual costs in the ranges of $2 to $11 million in the 2020s, $10 to $58 million in the 2050s, and $32 to $193 million by the 2080s. Adaptation may reduce these costs somewhat. In Table 9.2, we estimate the benefits associated with implementation of an asthma intervention program similar to the New York State Healthy Neighborhoods Program, which was found to reduce asthma hospitalization rates by approximately 24 percent within eight counties in New York State (Lin et al. 2004). The benefits of adapting monetarily increase in the future and eventually outweigh the costs of asthma intervention programs.

PART II. BACKGROUND

9.1 Public Health in New York State

The public health sector in New York State encompasses disease prevention and the promotion of healthy lifestyles and environments, as well as clinical medicine and the treatment of sick people. Within the state, 99% of health care spending is currently allocated to medicine while approximately 1% is spent on the public health system (Kinney, 2010). The county-based public health system in New York State is highly decentralized with non-uniform provision of its core services. According to the New York State Public Health Council, this decentralization of the public health service delivery system is a key obstacle for climate health preparedness (Kinney et al., forthcoming).

State GDP and Employment

The size of the public health sector is roughly reported in the official state GDP figures issued by the U.S. Bureau of Economic Analysis. The NAICS classification for public health is Health Care and Social Assistance, excluding Social Assistance, and the subsidiary parts are: Ambulatory Health Care Services, and Hospitals and Nursing and Residential Care Facilities. Employing more than 1.3 million people, the Health Care and Social Assistance industry accounted for 7% of the total state GDP in 2008 (New York State Department of Labor, 2008). For the 2008 current dollar state GDP figures, New York State GDP was $1.144 trillion; of this total, $82.580 billion was in the Public Health sector (United States Department of Commerce Bureau of Economic Analysis, 2009). See Table 9.3.

Table 9.3. 2007 New York State Census Data for Health Care and Social Assistance

Type of care/assistance	# Of establish-ments	# Of paid employees	Receipts/ revenue ($1,000)	Annual payroll ($1,000)
Health care and social assistance	53,948	1,326,039	128,595,239	54,422,381
Ambulatory health care services	38,284	439,960	46,191,651	18,512,293
Offices of physicians	17,279	134,142	21,801,478	8,589,789
Offices of dentists	9,101	50,896	6,124,859	1,993,816
Offices of other health practitioners	8,071	34,808	3,037,320	1,080,660
Outpatient care centers	1,454	43,522	4,330,922	1,875,468
Medical and diagnostic laboratories	924	16,433	2,967,253	999,220
Home health care services	944	144,246	6,432,091	3,444,280
Other ambulatory health care services	511	15,913	1,497,728	529,060
Hospitals	278	416,273	54,026,089	23,216,717
General medical and surgical hospitals	216	368,682	48,395,169	20,465,979
Psychiatric and substance abuse hospitals	44	25,258	2,073,753	1,220,277
Other specialty hospitals	18	22,333	3,557,167	1,530,461
Nursing and residential care facilities	5,048	237,061	15,820,321	7,160,538
Nursing care facilities	651	128,310	9,432,676	4,263,973
Residential mental health facilities	3,316	64,872	3,627,477	1,737,770
Community care facilities for the elderly	655	26,992	1,703,565	619,091
Other residential care facilities	426	16,887	1,056,603	539,704
Social assistance	10,338	232,745	12,557,178	5,532,833
Individual and family services	4,122	131,331	7,005,336	3,275,727
Emergency and other relief services	1,059	18,401	2,164,252	563,746
Vocational rehabilitation services	492	21,184	1,052,240	484,654
Child day care services	4,665	61,829	2,335,350	1,208,706

Source: United States Census Bureau 2010b

Health Care Expenditures

Billions of dollars are spent each year on the prevention and treatment of mortality and morbidity. In 2004, health care expenditures in New York State totaled approximately $126 billion (The Kaiser Family Foundation, 2007). Hospital care and professional medical care services accounted for over 50% of these health care expenditures statewide. See Table 9.4.

Table 9.4. Distribution of Health Care Expenditures (in millions), in 2004

	NY %	NY $	US %	US $
Hospital Care	36.10%	**$45,569**	37.70%	$566,886
Physician and Other Professional Services	23.20%	**$29,230**	28.20%	$446,349
Drugs and Other Medical Nondurables	14.10%	**$17,722**	13.90%	$222,412
Nursing Home Care	10.60%	**$13,364**	7.40%	$115,015
Dental Services	4.30%	**$5,445**	5.20%	$81,476
Home Health Care	4.80%	**$6,021**	2.30%	$42,710
Medical Durables	1.30%	**$1,685**	1.50%	$23,128
Other Personal Health Care	5.60%	**$7,040**	4.00%	$53,278
Total	100.00%	**$126,076**	100.00%	$1,551,255

Source: The Kaiser Foundation, 2007

9.2 Key Climate Change Sensitivities

Climate change is compounding existing vulnerabilities within New York State's public health sector. Changes in temperature, precipitation and sea level are anticipated to have adverse effects on air quality, disease and contamination, and mental health. Table 9.5 specifies which facets of climate change will impact the key economic components of the public health sector. See Kinney et al., forthcoming, for additional details.

Table 9.5. Climate Change Sensitivities: Public Health Sector (see Kinney et al., forthcoming)

Increases in mean temperature will affect air quality and the spread of disease and contamination
Increases in extreme heat events will contribute to more heat related deaths and air quality problems
Increases in mean precipitation will impact air quality, the spread of disease and contamination, and food production
Increases in storm surges and coastal flooding will contribute to mental health issues and the spread of disease and contamination **Decrease in soil moisture** could lead to greater risk of wildfires, which place residents at risk.

9.3 Impact Costs

Impact and adaptation costs in the public health sector are heavily interrelated. The level of impact is dependent upon preparedness, and adaptation strategies undertaken are dependent upon the type and severity of the impact. The following section presents costs associated with most common health vulnerabilities within New York State: heat waves, asthma and allergies, storms and flood, vector borne and infectious diseases, and food and water supply. Impact costs can be divided into three categories: morbidity, mortality, and lost productivity.

Although many aspects of public health are not easily quantifiable, the Environmental Protection Agency has approximated the value of a statistical life to be $6.9 million (See Kinney et al., forthcoming, "Economic Impacts of Mortality due to Heat Waves" for more information on estimating the value of a statistical life.) Other studies use substantially lower values. For this study, we used a range of estimates from $1.0 million to $6.9 million for the value of a statistical life.

Temperature-Related Deaths

Heat Waves. Heat waves are the leading cause of weather related deaths in the US and are anticipated to increase in magnitude and duration in areas where they already occur (Kalkstein & Greene, 1997; Knowlton et al. 2007). Heat events also lead to an increase in hospital admissions for cardiovascular and respiratory diseases (Lin et al. 2009). Without adaptation in New York State, there will likely be a net increase in morbidity and mortality due to heat waves. Fewer cold days should lower the number of cold-related deaths; however, new heat related deaths would outnumber these lives saved. The heat wave threat however may be a near term problem as it is expected that most homes will be climate controlled by the second half of this century. Adaptation costs will include air conditioning, but there is also a trend of increased air conditioning use in New York State (Kinney, 2010). This section presents various impact costs for heat waves that have occurred in other areas. Table 9.2 above contains estimates for heat impact costs in New York City.

Table 9.6 provides a summary of the costs associated with major heat waves that occurred in the U.S. over the past 30 years. Costs per heat event range from $1.8 billion to $48.4 billion (Kinney et al., forthcoming).

Table 9.6. Costs for Major Heat Waves in the United States, 1980-2000

Year	Event Type	Region affected	Total Costs / Damage Costs	Deaths
2000	Severe drought & persistent heat	South-central & southeastern states	$4.2 B	140
1998	Severe drought & persistent heat	TX / OK eastward to the Carolinas	$6.6-9.9 B	200
1993	Heat wave/ drought	Southeast US	$1.3B	16
1988	Heat wave/ drought	Central & Eastern US	$6.6B	5000-10,000
1986	Heat wave/ drought	Southeast US	$1.8-2.6B	100
1980	Heat wave/ drought	Central & Eastern US	$48.4B	10,000

Additional impact costs of extreme heat events outside New York State include:

- The number of premature deaths linked with hot weather events in Canada has been reported as 121 in Montreal, 120 in Toronto, 41 in Ottawa, and 37 in Windsor. The value per premature death, based on lost earning potential, is estimated at $2.5 million. These cities are spending an additional $7 million per year on health care (Kinney et al., forthcoming).

Concerning hospital admissions and extreme heat, Lin et al. (2009) found increased rates of hospital admissions for both cardiovascular and respiratory disorders in New York City. These effects, which were investigated for summer months between 1991 and 2004 were especially severe among elderly and Hispanic residents. As discussed in the Energy chapter, extended heat events may also be associated with increased likelihood of blackouts, with compounding effects on public health. In a study of the health impacts in New York City of the 2003 blackout, Lin et al. (2010) found that the blackout event had a stronger negative effect on public health than comparable hot days. In particularly, the study found that mortality and respiratory hospital admissions increased significantly (2 to 8 fold) during the blackout event (Lin et al. 2010).

Cardiovascular Disease. Extreme temperature events have been linked to higher rates of premature death and mortality among vulnerable populations, including children, elderly, and people suffering from cardiovascular or respiratory conditions (Kinney et al., forthcoming). Cardiovascular disease is a predisposing factor for heat related deaths because it can interfere with the body's ability to thermoregulate in response to heat stress (Kinney et al., forthcoming). Table 9.7 includes information on the costs of treating and suffering from cardiovascular disease. Nearly $16 billion was spent on cardiovascular disease in New York State in 2002. This number will likely increase as temperatures continue to climb.

- The costs associated with treating CVD and stroke in the U.S. in 2009 were expected to exceed $475 billion, with estimates of direct costs reaching over $313 billion. Although not all such costs are related to extreme heat events, CVD prevalence is likely to be exacerbated during such periods, thereby putting additional strain on the Public Health System and its efforts to reduce CVD incidence. Costs are projected to increase in future decades, as the size of the elder population is also expected to grow. (Kinney et al., forthcoming). As noted earlier, nearly $16 billion was spent on cardiovascular in 2002 disease in New York State alone.

Table 9.7. New York State Costs for Cardiovascular Disease, 2002 (in Millions of dollars)

Type of Cost	Coronary Heart Disease	Stroke	Congestive Heart Failure	Total Cardiovascular Disease
Direct Costs				
Hospital/Nursing Home	$3,751.20	$1,189.20	$828.10	$6,120.90
Physicians/Other Professionals	$771.80	$116.50	$86.00	$1,451.40
Drugs/Other	$0.00	$0.00	$0.00	$0.00
Medical Durables	$556.40	$38.80	$107.60	$1,543.60
Home Health Care	$143.60	$150.50	$129.10	$567.90
Total direct expenditures	$5,223	$1,495.00	$1,150.80	$9,683.80
Indirect Costs				
Lost Productivity/Morbidity	$753.80	$271.80	NA	$1,499.90
Lost Productivity/Mortality	$4,056.30	$631.00	$96.80	$4,795.80
Total indirect expenditures	$4,810.20	$902.90	$96.80	$6,295.70
Grand Totals	$10,033.20	$2,397.90	$1,247.60	$15,979.50

Source: http://www.nyhealth.gov/diseases/cardiovascular/heart_disease/docs/burden_of_cvd_in_nys.pdf

Asthma and Allergies

The spending on asthma, allergies, and respiratory problems in New York State is anticipated to increase with climate change (Kinney, 2010). Current spending on asthma in the U.S. is on the order of $10 billion per year. Within New York State, spending on asthma-related hospitalizations exceeded $535 million in New York State in 2007 (NYSDOH 2009). As described in Table 9.2 and below, asthma hospitalization costs may increase as the result of higher levels of ambient ozone with climate change. Asthma-related spending is also likely to increase as heat, higher levels of CO_2, increased pollen production, and a potentially longer allergy season (or shift in the start date of the season) may increase cases of allergies and asthma in New York State (Kinney, 2010).

Vulnerable populations, including children and the elderly, poor, and those with predisposing health conditions, face the greatest threats and therefore costs. Consider, for example, the costs of childhood asthma. Children are among those most vulnerable to the public health impacts of climate change. One study found that the average per capita asthma-related expenditures totaled $171 per year for US children with asthma -- $34 for asthma prescriptions, $31 for ambulatory visits for asthma, $18 for asthma ED visits, and $87 for asthma hospitalizations. Average yearly health care expenditure for children with asthma were found to be $1129 per child compared with $468 for children without asthma, a 2.8-fold difference (Lozano et al, 1999). Within New York State, the cost for asthma hospitalizations for children

15 and under between 2005 and 2007 exceeded $317 million (NSYDOH, 2009). Such costs are likely to increase as the result of climate change.

Ambient Ozone

Many areas within New York State do not meet the health-based National Ambient Air Quality Standards for ozone. Surface ozone formation is anticipated to increase with climate change, as a result of changing airmass patterns and rising temperatures (the latter leads to an increase in the emissions of ozone relevant precursors from vegetation) (Kinney 2008). Unhealthy levels are reached primarily during the warm half of the year in the late afternoon and evening. Asthmatics and people who spend time outdoors with physical exertion during high ozone episodes (i.e. children, athletes, and outdoor laborers) are most vulnerable to ozone and respiratory disease because of increasing cumulative doses of ozone to the lungs (Kinney et al., forthcoming). Recent estimates by Knowlton et al. (2004) and Bell et al. (2007) indicate that climate change is likely to cause significant increases in both asthma hospitalizations and asthma mortality in New York City. Knowlton et al. (2004) project a median increase in asthma mortality of 4.5 percent for the New York Metropolitan region by 2050. Bell et al. (2007) project an increase of 2.1 percent average in asthma hospitalizations across all U.S. cities included in the study. At the 95 percent confidence level, Bell et al.'s (2007) estimates range from .6% to 3.6%. This range of values is used in Table 9.2 above.

Storms and Floods

Storms and coastal and inland flooding will result in the loss of lives and property, as well as cause physical injury, mental distress, and the spread of disease and contamination. More intense storms are anticipated to disrupt energy and communication infrastructure, which will adversely impact public health as the sector has recently become increasingly dependent on high-quality, high-speed telecommunications (NYCEDC, DoITT, & DSBS, 2005, p. 9).

Emergency preparedness and response are crucial components of the public health sector and its ability to forewarn and respond to extreme storms. More extreme events may require better and more extensive emergency response systems, particularly with respect to coastal storms and flooding and ice storms. There will be costs associated with protecting the public from injury and death as the result of more frequent extreme events. The state currently has emergency response systems in place, e.g. DOT, to keep sectors running smoothly during and after storms. These systems will need to be expanded to deal with more frequent and severe extreme events (Kinney, 2010).

Vector-Borne and Other Infectious Diseases

Changes in temperature and precipitation will affect the patterns of vector-borne and other infectious disease in New York State, likely increasing the incidence of West Nile and Lyme Disease. This may require more spending on pest management and vaccinations and enhancement of existing surveillance programs.

Arthropod vectors, transmitters of infectious disease, are extremely sensitive to climate change because population density and behavior are correlated with ambient air temperature, humidity, and precipitation. West Nile Virus and Lyme Disease are particularly prevalent in New York City, Long Island, and Hudson Valley due to favorable climate conditions for vectors (Kinney et al., forthcoming), and human exposure is generally expected to increase as New York State gets wetter and warmer (Kinney et al., forthcoming).

Water Supply and Food Production

The increased cost of water treatment to ensure public health safety in the face of more extreme storm events (e.g. cost of treating additional turbidity) will likely become one of the most significant economic costs within this sector (Kinney, 2010). See also Chapter 2: Water Resources and Chapter 5: Agriculture for a more complete discussion of the economic costs associated with maintaining a secure and reliable supply of water and food.

9.4 Adaptation Costs

Adaptations are wide-ranging and constantly evolving in the public health sector. Cost are incurred through measures to improve the health protection system to address climate change, introduce novel health interventions, meet environmental and health regulatory standards, improve health systems infrastructure, occupational health, research on reducing the impact of climate change, and the prevention of additional cases of disease due to climate change (Parry et al, 2009, p.53).

Because climate change in New York State will mainly alter the frequency of existing health care problems, public health and environmental agencies in New York State are already involved in activities that address climate change vulnerabilities. The most effective adaptation strategy will be to further integrate climate change information into ongoing public health surveillance, prevention, and response programs. Additional investment should be made in comparative health risk assessments, environmental monitoring and reporting, communication and information dissemination, and environment-health crosscutting initiatives. This section discusses potential costs of adaptation to climate change in the public health sector in New York State. While some of adaptation measures and costs described below are based on studies of New York State, others are based on studies conducted in other states in the Northeast or in other parts of the United States. Additional, detailed analysis of the feasibility and costs of these measures is needed to ensure that they would be appropriate and effective in New York State.

Temperature-Related Deaths

Heat Watch/Warning Systems. Early warning systems for extreme heat events are an effective method to reduce heat-related morbidity and mortality. One example of an effective program that may apply to New York is that The Philadelphia Hot Weather–Health Watch/Warning System (PWWS). PWWS was developed in 1995 to serve as an early warning system for extreme heat events. Ebi et al.'s 2004 study examined the costs and benefits of the system and concluded that if any lives are saved, then the system has significant benefits. The VSL for even one life is greater than the cost of running the system. These findings are based on the additional wages required to pay workers to run the system, totaling around $10,000 per day.

Over a three-year period between 1995 and 1998, the City of Philadelphia issued 21 alerts, and costs for the system were estimated at $210,000. The value of 117 lives saved over the same time period were estimated to be $468 million; therefore the net benefits of the issued heat wave warnings were estimated to be nearly $468 million for the three-year period (Ebi et al, 2004; Kinney et al., forthcoming). In Table 9.2 above, results from the Ebi study are used to develop estimates of adaptation costs and benefits of a similar heat wave warning system for New York State.

Air Conditioning and Cooling Centers

Expanded use of air conditioning is another important adaptation to extreme heat. As described above, New York City has initiated a program to provide free air conditioners to elderly residents who are unable to afford them at a program cost of approximately $1.2 million for each year 2008 and 2009. The program entailed distribution of approximately 3000 air conditioning units to residents over 60 years old (Sheffield, 2010). Substantial expansion of this type of program may be needed to foster adaptation to climate change, given that high number of at-risk seniors not only in New York City but throughout the state. As noted, other on-going efforts to reduce heat related mortality in New York include development of a network of cooling centers to help residents cope with extreme heat.

Asthma Prevention

Prevention of asthma hospitalizations is a priority for New York State (New York State Department of Health 2005). One option for prevention of asthma hospitalizations entails implementation of a statewide program similar to the New York State Healthy Neighborhoods Program. In this program, which was implemented in eight New York counties between 1997 and 1999, outreach workers initiated home visits and also provided education about asthma, asthma triggers, and medical referrals. The program was found to reduce asthma hospitalization rates by approximately 24 percent within eight counties in New York State (Lin et al. 2004). Such a program may help reduce additional hospitalizations as the result of climate change.

Vector-Borne and Other Infectious Diseases

*Vector Control***.** Without adaptation, cases of West Nile virus may increase in New York State. One potential adaptation option is aerial spraying to control mosquito populations. The benefits of this type of spraying have been found to outweigh the costs in other parts of the country. For example, 163 human cases of West Nile virus (WNV) disease were reported during an outbreak in Sacramento County, California in 2005. Emergency aerial spraying was conducted by the Sacramento-Yolo Mosquito and Vector Control District In response to WNV surveillance indicating increased WNV activity. The economic impact of the outbreak included both vector control costs and the medical cost to treat WNV disease. Approximately $2.28 million was spent on medical treatment and patients' productivity loss for both West Nile fever and West Nile neuroinvasive disease. Vector control costs totaled around $701,790 for spray procedures and worker's overtime hours. The total economic impact of WNV was $2.98 million. A cost-benefit analysis indicated that only 15 cases of West Nile neuroinvasive disease would need to be prevented to make the emergency spray cost-effective (Barber et al, 2010).

Vaccination. Another option for adapting to increased threats of vector-borne disease entails vaccination programs. Such programs can be a cost-effective means to reduce the public health impacts of climate change. An evaluation of the cost effectiveness of vaccinating against Lyme disease in Atlanta, GA revealed that there may be substantial economic benefits from vaccination. Within the study, a decision tree was used to examine the impact on society of six key components, including the cost per case averted. Assuming a 0.80 probability of diagnosing and treating early Lyme disease, a 0.005 probability of contracting Lyme disease, and a vaccination cost of $50 per year, the mean cost of vaccination per case averted was $4,466. Increasing the probability of contracting Lyme disease to 0.03 and the cost of vaccination to $100 per year, the mean net savings per case averted was found to be $3,377. Because most communities have average annual incidences of Lyme disease <0.005, economic benefits will be greatest when vaccination is used on the basis of individual risk, especially for those whose probability of contracting Lyme disease is ≥0.01 (Meltzer et al, 1999, p. 321-322).

In addition to known diseases such as West Nile virus, climate change may also bring emerging diseases to New York State, or lead to the introduction of diseases that are present in more tropical climates. There will be a need to monitor for new diseases as part of the public health system (Kinney, 2010). Options for treatment or prevention of these new diseases will be an important public health priority.

9.5 Summary and Knowledge Gaps

The public health system in New York State is highly decentralized and county-based, with non-uniform provision of its core services. According to the state's Public Health Council, this decentralization of the public health service delivery system is a key obstacle for climate health preparedness (Kinney et al., forthcoming). Adaptations within this sector will help lessen the impacts of climate change on resident's health and investment in preparedness infrastructure will also enhance the effectiveness of the day-to-day operations of the public health system (Kinney et al., forthcoming).

Knowledge gaps and areas for further action include:

- Additional monitoring of emergent diseases and development of effective options for treatment and vaccination;

- Additional monitoring of threats to food and water supplies and development of appropriate strategies to reduce these threats;

- Expansion of emergency preparedness planning throughout the state in order to prepare for more frequent and severe extreme climate events;

- Expansion of community-based public health warning systems for extreme heat; and

- Expansion of programs to reduce asthma-related hospitalizations.

Maintenance of public health is linked with other sectors and adaptation within other sectors is likely to be as important as the enhancement of conventional public health practices for reducing the health impacts of climate change. That is, if we take care of adaptation in these other sectors, then the public health costs of climate change will be manageable (Kinney, 2010). Particularly, disaster mitigation, food and water security, and infrastructure improvements will significantly reduce the impacts of climate change on public health (Parry et al, 2009, p.52).

Technical Notes – Public Health Sector
Impact: Heat-related deaths
Adaptation: Create a heat watch/warning system similar to Philadelphia

Assumptions

- From ClimAID Ch. 11 Case Study, "Projecting Temperature-Related Mortality Impacts in New York City under a Changing Climate"
- Based on a 2.4% GDP growth rate *(*United States Department of Commerce Bureau of Economic Analysis*,* nd.)
- $7.4 million ($2006), Environmental Protection Agency (EPA) Value of a Statistical Life (VSL) (USEPA 2000, 2010). (The use of the EPA value for VSL was suggested by the New York State Department of Health).
- 30X to 604 temperature-related deaths per year for New York County (Kinney et al., forthcoming; and Kalkstein and Greene 2007)
- Calculated based on the findings of Ebi, et al., 2004 study of the Philadelphia Hot Weather – Health Watch/Warming System (PWWS) that estimated the system saved 117 lives between 1995 and 1998
- Based on 2000 population data for New York County (Manhattan) (1,537,195) and Philadelphia County (1,517,542) (United States Census Bureau, 2000a)
- Based on average costs to run the PWWS. Actual expenses vary from year-to-year.

Annual costs of current and future climate hazards without climate change:

1. Project out the $7.4M VSL ($2006) to 2080 using a 2.4% GDP growth rate to find the VSL for 2020, 2050, and 2080.
2. Using these VSL projections, estimate future costs of lives lost by multiplying the respective values by the projected number of lives lost in New York State due to temperature-related deaths per year under both the low and high scenario to find the totals.

Annual incremental costs of climate change impacts without adaptation:

3. Multiply the heat-related mortality projections under climate change in the ClimAID chapter figures by the respective future VSL estimates to find the projected costs of climate change -related deaths.

Annual benefits of adaptation:

4. Based on the estimated number of lives saved from the Philadelphia Hot Weather-Health Watch/Warning System (PWWS) over a three-year period (117), find the annual lives saved by dividing by 3 (39). In order to ascertain what percentage of the population was saved by PWWS, divide number of lives saved per year (39) by the total population of Philadelphia County (1,517,542) (0.0026%).
5. Using this percentage, estimate the total number of New York City deaths that could be saved by a similar system. Assuming that twice the New York County population is

vulnerable to temperature-related deaths, multiply 0.0026% by twice the New York County population: (0.0026% x (2 x 1,537,195)) = 79.

6. To find economic benefit from the number of lives saved, multiply the future VSL estimate (step 1) by the estimated number of lives saved in New York City (79 from step 8).
7. Project this benefit out to 2080 using the 2.4% GDP growth rate.

Annual costs of adaptation:

8. The PWWS study that found it cost approximately $210,000 to run the system over 3 years. Therefore the average annual cost of the system is $70,000 (=$210,000/3). Find the per person annual cost of the PPWS by dividing the annual cost by the number of people in Philadelphia County ($70,000/1,517,542=$0.05).
9. Find the annual cost to NYC by multiplying the estimated vulnerable population (step 8) by the annual per person cost to run the system (step 12) (3,074,390 x $0.05=$141,813).

Impact: Cold-related deaths
Adaptation: None

Assumptions

- From Kinney et al. (forthcoming) Case Study, "Projecting Temperature-Related Mortality Impacts in New York City under a Changing Climate"
- Based on a 2.4% GDP growth rate.
- $7.4 million ($2006) Environmental Protection Agency (EPA) Value of a Statistical Life (VSL) (USEPA 2000, 2010).

Annual costs of current and future climate hazards without climate change:

10. Using the estimated cold-related deaths of 18 in New York County per year for the baseline period of 1970-1999) from Kinney et al. (forthcoming), calculate the current VSL costs of cold-related deaths.
11. Project out the VSL values to obtain values for 2020, 2050, and 2080.
12. Using these VSL projections, estimate future costs of lives lost by multiplying the respective values by the projected number of lives lost in New York State due to cold-related deaths per year.

Annual incremental costs of climate change impacts without adaptation:

13. Reduce the cold-related death projections given in Kinney et al. (forthcoming) for each timeslice to scale up to New York State.
14. Multiply these figures by the respective future VLS estimates to find the projected reductions in costs due to reduced temperature-related deaths.

Impact: Asthma

Adaptation:

Implementation of a statewide New York Health Neighborhoods program. This program was found to reduce asthma related hospitalizations by 24% between 1997 and 1999 in the eight counties where it was implemented (Lin et al. 2004).

Assumptions

- Based on a 2.4% GDP growth rate.

Annual costs of current and future climate hazards without climate change:

1. Asthma hospitalizations cost the state approximately $535 million in 2007 (New York State Department of Health (2009). In 2007, the average cost per asthma hospitalization in New York State was $14,107 (NYSDOH 2009).

2. These costs are each assumed to increase over time at a rate of 2.4% based on the midpoint growth rate of GDP.

Annual incremental costs of climate change impacts without adaptation:

3. Bell et al. (2007) provide estimates of the number of additional asthma hospitalizations U.S. cities as the result of the climate change in 2050. These values were extrapolated to obtain estimates for 2020 and 2080. Costs were estimated based on the cost of hospitalization in each year multiplied by the number of additional projected hospitalizations.

Annual costs of adaptation

4. Lin et al. (2004) provide data on the annual cost of the New York State Healthy Neighborhoods program in eight counties in New York State. These costs were assumed to increase at an average rate of 2.4% per year, and were extrapolated to the state as a whole to obtain estimates of the costs of adaptation in 2020, 2050 and 2080.

Annual benefits of adaptation:

5. Lin et al. (2004) found that the New York Healthy Neighborhoods program reduced asthma hospitalizations by 24 percent in New York State. A similar reduction rate was used for climate change-related hospitalizations in order to obtain estimates of the benefits of adaptation.

$US 2010 adjustment:

The final calculations in tables 9.1 and 9.2 were adjusted to $US2010 using the United States Bureau of Labor Statistics CPI Inflation Calculator, http://data.bls.gov/cgi-bin/cpicalc.pl to yield the final calculations.

10 Conclusions

This study has aimed to provide an overview assessment of the potential economic costs of impacts and adaptation to climate change in eight major sectors in New York State. It builds on the sectoral knowledge of climate change impacts and adaptation developed in the ClimAID Assessment Report as well as on economic data from New York State and analyses of the costs of impacts and adaptations that been have conducted elsewhere. This chapter presents the principal conclusions of the study.

Costs of impacts and adaptation are expected to vary across sectors in New York State, with some sectors more at risk to climate change than others and with some sectors potentially requiring more costly adaptations. Because New York is a coastal state, and because of the heavy concentrations of assets in coastal counties, the largest impacts in dollar terms will be felt in coastal areas, including impacts on transportation, other coastal infrastructure, and natural areas. There will be significant costs of climate change and needs for adaptation throughout the state: climate change is truly a state challenge. From the evidence assessed in this study, it appears that climate costs for the sectors studied without adaptation in New York State may approach $10 billion annually by midcentury. However, there also appears to be a wide range of adaptations that, if skillfully chosen and scheduled, can markedly reduce the impacts of climate change in excess of their costs. This is likely to be even more true when non-economic objectives, such as the environment and equity, are taken into account.

All sectors will have significant additional costs from climate change. The sectors that will require the most additional adaptations include transportation, the coastal zone, and water resources. Communications and agriculture are sectors in which costs could be large if there is no adaptation; but in these sectors, adaptation to climate is a regular part of investment, so that additional costs are likely to be moderate. This is also true to some extent of the energy sector. The ecosystem sector will see also significant impacts, but many of these costs estimates are preliminary and require further assessment. Finally, public health will be significantly impacted by climate change, but many of these impacts can be avoided with appropriate adaptations.

10.1. SECTOR RESULTS

Water Resources. Water supply and wastewater treatment systems will be impacted throughout the state. Inland supplies will see more droughts and floods, and wastewater treatment plants located in coastal areas and riverine flood plains will have high potential costs of impacts and adaptations. Adaptations are available that, as suggested in the case study for this sector, will have sizable benefits in relation to their costs.

Coastal Zones. Coastal areas In New York State have the potential to incur very high economic damages from a changing climate due to the enhanced coastal flooding as the result of sea level rise and continued development in residential and commercial zones, transportation infrastructure (treated separately in this study), and other facilities. Adaptation costs for coastal areas are expected to be significant, but relatively low as compared to the potential benefits.

Transportation. The transportation sector may have the highest climate change impacts in New York State among the sectors studied, and also the highest adaptation costs. There will be effects throughout the state, but the primary impacts and costs will be in coastal areas where a significant amount of transportation infrastructure is located at or below the current sea level. Much of this infrastructure floods already, and rising sea levels and storm surge will introduce unacceptable levels of flooding and service outages in the future. The costs of adaptation are likely to be very large and continuing.

Agriculture. For the agriculture sector, appropriate adaptation measures can be expected to offset declines in milk production and crop yields. Although the costs of such measures will not be insignificant, they are likely to be manageable, particularly for larger farms that produce higher value agricultural products. Smaller farms, with less available capital, may have more difficulty with adaptation and may require some form of adaptation assistance. Expansion of agricultural extension services and additional monitoring of new pests, weeds and diseases will be necessary in order to facilitate adaptation in the agricultural sector.

Ecosystems. Climate change will have substantial impacts on ecosystems in New York State. For revenue-generating aspects of the sector, including winter tourism and recreational fishing, climate change may impose significant economic costs. For other facets of the sector, such as forest-related ecosystems services, heritage value of alpine forests, and habitat for endangered species, economic costs associated with climate change are more difficult to quantify. Options for adaptation are currently limited within the ecosystems sector and costs of adaptation are only beginning to be explored. Development of effective adaptation strategies for the ecosystems sector is an important priority.

Energy. The energy sector, like communications, is one in which there could be large costs from climate change if ongoing improvements in system reliability are not implemented as part of regular and substantial reinvestment. However, it is expected that regular investments in system reliability will be made, so that the incremental costs of adaptation to climate change will be moderate. Even with regular reinvestments there may be increased costs from climate change. Moreover, the energy sector is subject to game-changing policy measures such as impacts on demand from a carbon tax (either directly or via cap and trade) and from the large investments in stability that could be undertaken to deal with the impacts of electromagnetic storms.

Communications. The communications sector is one in which there could be large costs from climate change if ongoing adaptations are not implemented as part of regular reinvestment in the sector or if storms are unexpectedly severe. However, it is expected that regular adaptations will be made, so that additional costs of adaptation for climate change will be relatively small.

Public Health. Public health will be impacted by climate change to the extent that costs could be large if ongoing adaptations to extreme events are not implemented. Costs could also be large if appropriate adaptations are not implemented in other sectors that directly affect public health, particularly water resources and energy. The costs associated with additional adaptations within the public health sector need further study.

10.2. SUMMARY

This study is an important starting point for assessing the costs of climate change impacts and adaptations in New York, although much further work needs to be done in order to provide detailed estimates of comprehensive costs and benefits associated with climate change. This work will have to deal with challenges such as the lack of climate-focused data sets and the fact that the feasibility of many potential adaptations has not been adequately analyzed. On the other hand, the basic conceptual approaches to future work have been identified, and even initial cost-benefit analyses of major impacts and corresponding adaptation options can help to illustrate the economic benefits of adaptation and thus to shape policy.

In terms of costs of adaptations, higher costs are projected for the Transportation sector, with its extensive capital infrastructure and less but still significant costs are projected for the Health, Water Resources, Ocean and Coastal Zones, Energy, and Communications sectors. Costs for adaptations in the Agriculture Sector are projected to be moderate, and costs for adaptations in the Ecosystems Sector require further assessment.

Net benefits comparing avoided impacts to costs of adaptation are most favorable for the Public Health and Ocean and Coastal Zones sectors, more moderate but still significant for the Water Resources, Agriculture, Energy, and Transportation sectors, and low for the Communications sector.

Planning for adaptation to climate change in New York State should continue to build on the State's significant climate change adaptation planning and implementation efforts to date, including further assessments of specific adaptation strategies. Benefits from adaptation are likely to be significant because there are many opportunities for development of resilience in all sectors and regions.

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