Modern tunnel pumps have a capacity of at least 1,000 to 1,500 gallons per minute per pump.[41] If four such pumps per tunnel could be mobilized in an emergency situation (working one pump on each of the two tracks, and from either end of the tunnel simultaneously), the pumping capacity would be about 4,000 to 6,000 gallons per minute per tunnel, or 5.8 million to 8.6 million gallons per day per tunnel, with an average of approximately 7.2 million gallons per day per tunnel.

If all 14 tunnels crossing the river were to fill with water, it would take about five days of pumping per tunnel to clear them of water. This assumes that the pumping capacity (on average) is available to pump out the flooded subway tunnels during an emergency situation, and that such pumping will occur in parallel for each of the 14 river crossing tunnels, each with an average volume of about 35 million gallons of water. It is questionable, however, whether pumping all the tunnels

	Type of Delay			1%/y BFE		BFE +2ft		BFE +4ft	
1	Surge Duration, D++			≤1		≤1		≤1	
2	Restore Power, E			≤1		≤1.5		≤2	
3	Logistics Set-Up, L |P>0			≤1		≤2		≤3	
4	Max{D, E, L}			≤1		≤2		≤3	
5	Facility	LCE (ft)	Z_i (ft)	Max{P,A,R}	T90 (days)	Max{P,A,R}	T90 (days)	Max{P,A,R}	T90 (days)
6	Lincoln Tunnel*	22.6*	Z5=9	{0,0,0}	T=1	{0,0,1}	T=1	{0,0,1}	T=2
7	Holland Tunnel*	12.1*	Z5=9	{0,0,0}	T=1	{0,0,1}	T=1	{3,2,6}	T=9
8	Queens-Midtown T.	9.5	Z2=11	{1,1,1}	T=2	{4,2,4}	T=6	{6,2,7}	T=10
9	Brooklyn-Battery T.	7.5	Z1=9	{2,1,2}	T=3	{5,3,6}	T=6	{6,3,7}	T=10
10	PATH System	9.9	Z5=9	{0,1,1}	T=2	{6,3,7}	T=9	{7,3,8}	T=11
11	LIRR/Amtr ERvr 42ndStr T	7.9	Z2=11	{6,3,10}	T=11	{6,3,11}	T=13	{6,3,12}	T=15
12	NJTHudsonTubesPennSt	8.9	Z5=9	{5,3,7}	T=8	{7,3,11}	T=13	{7,3,12}	T=15
13	NJT ARC Tunnel**	11.5	Z5=9	{0,0,0}	T=1	{0,0,0}	T=1	{5,2,7}	T=10
14	LIRR 63rdStrE-River>GCT	11.6	Z2=11	{0,0,0}	T=1	{7,3,11}	T=13	{8,3,10}	T=13
15	to GCT via Steinway T.	9.9	Z2=11	{6,3,10}	T=11	{7,4,11}	T=13	{8,5,12}	T=15
16	NYC Subway System	≥5.9	Z5=9	{7,5,20}	T=21	{8,6,23}	T=25	{9,7,26}	T=29
17	MNR Hudson Line along Harlem River (SpuytenDvl.Stn.)	6.6	Z4=8	{0,2,3}	T=4	{0,3,6}	T=8	{0,4,9}	T=12
	Bridge Access Ramps+ to								
18	MarineParkw-Rockaway	6.9	Z8=9	{0,0,0}	T=1	{0,1,1}	T=2	{0,1,2}	T=4
19	CrossBayBrdChnlRockaw.	6.9	Z8=9	{0,0,0}	T=1	{0,1,1}	T=2	{0,1,2}	T=4
20	ThrogsNeck	8.9	Z1=14	{0,0,0}	T=1	{0,1,1}	T=2	{0,1,2}	T=4
21	BronxWhitestone	10.9	Z1-2=12.5	{0,0,0}	T=1	{0,1,1}	T=2	{0,1,2}	T=4
22	RFK (Triboro)	13.9	Z3-2=10	{0,0,0}	T=1	{0,0,0}	T=1	{0,1,1}	T=2
23	Verrazano-Narrows	7.6	Z5=9	{0,0,0}	T=1	{0,1,0}	T=2	{0,1,0}	T=2
	Airports:								
24	JFK	10.6	Z7=8	{0,0,0}	T=1	{0,1,1}	T=2	{1,3,4}	T=6
25	LaGuardia*	10.0*	Z2=11	{2,2,3}	T=3	{3,2,4}	T=4	{3,2,6}	T=8
26	Newark	9.2	Z5a=8	{0,0,0}	T=1	{0,1,2}	T=3	{0,2,3}	T=5
27	Teterboro	3.9	Z5a≤8	{0,1,1}	T=2	{0,2,2}	T=3	{0,2,3}	T=5
28	Marine Ports:			Information currently not available					
29				Scenario 1		Scenario 2		Scenario 3	
30	T90 (days)			1 to 21		1 to 25		2 to 29	

Note: BFE and Zi = average and area-weighted base flood elevation (see Table 9.13); LCE = lowest critical elevation; D = surge duration; E = electric grid restoration time; L = logistic set-up time; P = pumping time; A = damage assessment time; R = repair time.
Flood color code: Red, Orange, Green: when Zi > LCE, for Scenario 1, 2, and 3, respectively. Dark grey: No Flooding (i.e. LCE > Zi)
* Except emergency-operational measures for Holland, Lincoln, and some PATH tunnels and LaGuardia airport (levees)
** Assumes that passenger connection (LCE=9.65 feet) between existing Penn Station (LCE=8.9 feet, Z5=9 feet) and the New Penn Station Extension will be gated.
\+ Assuming that bridges will be open to the public without toll collection, as some toll booths and/or EZ Pass equipment may be undergoing assessments and repairs.
++The duration during which the storm surge exceeds the LCE of any given structure varies between structures. For the 100-year storm these variations range from minutes to a few hours. Depending on this duration and the area of openings of the structure, it fills either partially or entirely.

Table 9.5 Estimates of number of days contributing to T90, the time needed to restore a transportation system to ~ 90% functionality, without adaptation measures except as noted at the same time is logistically possible. Therefore, five days is the minimum amount of time it would take under a best-case scenario; one week per tunnel is, perhaps, more realistic. The river subway tunnel operations alone would require 56 powered mobile pumps (four in each of the 14 tunnels) (see subsequent sections in this case study).

Assuming that the land-based tunnels can be pumped out more or less during the same time as the generally deeper river-crossing tunnels, the operation may need something in the order of 100 such pumps if pumping is to be achieved within one week. A smaller number of pumps, or not pumping all tunnels simultaneously, would lengthen the pumping time required.[42]

Rigorous, engineering-based assessments, combined with logistic management plans of how to procure such pumping capacity simultaneously, are urgently needed that can determine more precise estimates of the pumping system needs for New York City metropolitan-area tunnels.

The environmental impacts on the waters in the New York Harbor estuary from the simultaneous pumping activities could be significant and would be in addition to those from the debris and spills from surface sources, including toxic sites that were reached by the floodwaters. It is assumed that environmental emergency permits for disposing of the pumped tunnel waters are pre-event approved and would require no extra processing times. If pre-event approved permits do not exist, then additional delays may need to be assumed.

Such a storm as analyzed in the ClimAID assessment not only damages flooded tunnels, but also affects external support systems (power, communication, logistic preparations) needed for the pumping operations, subsequent inspection of damage in the tunnels, and to make the necessary repairs. The total

Scenario	Flooded Tunnel Volume	Flooded Tunnel Length
S1 1%/y BFE*	400 million gallons	60,000 ft
S2 +2ft SLR	408 million gallons	60,600 ft
S3 +4ft SLR	411 million gallons	61,000 ft

* BFE = base flood elevation
Note: Flooded tunnel volume and flooded tunnel length for each of the S1, S2, and S3 sea level scenarios.

Table 9.6 Estimated total volume of flood-prone subway tunnels

projected outage times for transportation systems are summarized in **Table 9.5**.

The estimates of recovery times given in **Table 9.5** remain highly uncertain and may change substantially when the necessary engineering vulnerability and risk assessments of complex systems are performed in sufficient detail and when the emergency response capability of transportation operators can be quantified. Such assessments may take years for some of the more complex and older transportation systems, where the as-built or current state of repair information is not always readily available. Each operating agency will need to make these assessments in years to come before a more realistic picture will emerge for the expected damage and costs to the operating agencies and of the economic impact to the public (see Section 9.5.7).

For instance, there are likely to be other significant restraints on the ability of the NYCT subway system to recover from flooding that have not been incorporated into this analysis. Even if emergency pumping can be implemented, the impact of salt, brackish, and/or turbid water will last long after the water itself is removed. Deposits will need to be cleaned from signal equipment and controls, which may need to be replaced either in total or by component, and only very limited service could be provided after pumping is completed until signals are restored. Much of the equipment in the subways is of a specialized nature that requires orders from manufacturers with long lead times, especially for significant quantities. There probably are not enough personnel trained to rebuild and refurbish equipment simultaneously in multiple subway lines even if the equipment could be procured. There is some existing equipment that, if damaged, cannot be replaced because it is obsolete and is no longer manufactured, nor are there replacement parts for it. Such equipment would have to be redesigned and then installed—a process that can take a long time.

Finally, if significant soil movement or washouts occur, it is likely that structures throughout the system may experience some settlement, and there could be structural failure of stairs, vent bays, columns, etc.

Together, such conditions could easily extend the time it takes to restore to a 90-percent functionality of the subway system (**Table 9.5**) by three to six months (and perhaps longer). It is estimated that permanent restoration of the system to the full revenue service that was previously available could take more than two years.

In general, adaptation options (see sections 9.4, 9.6.2, and subsequent sections of this case study) will need to be carefully evaluated to arrive at a better understanding of the resources that will be needed to make the coastal and estuarine New York State transportation systems resilient to all types of climate change impacts, and to sea level rise in particular.

Methods for Calculating Restoration Time to 90 Percent of Functionality (T90, measured in days)

Table 9.5 represents ClimAID's best effort to combine stakeholder-provided information and publicly available data into outage/restoration time estimates. It is the basis for the case study, and contains key information, in compact numeric form.

The restoration time T90, after which a transportation system regains 90 percent of its pre-storm functional capacity, is computed for various transport systems as follows (see red numbers in columns 4, 5, and 6 in **Table 9.5**):

Equation 2. $T90\ (\text{days}) = \text{Max}\{D, E, L|P>0\} + \text{Max}\{P, A, R\} \geq 1$

All units are in days. The operator $\text{Max}\{x_1, x_2, x_3\}$ chooses the largest value of the values xi , where **D** is the surge duration; **E** is the electric grid restoration time; **L** is logistic set-up time (note that $L|P>0$ means that L is only counted when there is a finite pumping time $P>0$; otherwise $L=0$ since there is no logistic set-up time when pumping is not needed); **P** is pumping time; **A** is damage assessment time; and **R** is repair time. The maximum (largest value) rather than the sum of **D, E, L** is chosen since it is assumed that these times run largely in parallel, rather than being additive, although this choice may lead to underestimation of outage times from these causes.

A similar parallel set of activities is assumed between **P**, **A**, and **R**, although that may be even more optimistic. A minimum of $T90 \geq 1$day is imposed on all facilities, assuming that even if all six variables were close to zero, the public would avoid using transport for general economic activity (businesses may be closed) on the day of the storm, and mass transit would largely be reserved for emergency evacuation according to NYC's emergency plans. For road tunnels the time for accessibility by emergency and essential traffic (repair crews, utilities, etc.) may be shorter than those shown, which are meant to indicate when the facility becomes operational for the general public. In **Table 9.5**, rows 1–4 address the first term, and rows 5–27 the second term of equation 2.

There are large uncertainties with each of these variables, and also for the functional relationships between them. It is possible to devise alternatives to equation 2. **D** is in most cases less than one day, but a stalled nor'easter storm could extend **D** from one to a few tidal cycles (roughly 12 hours apart) to as much as a few days. **E**, electricity restoration time, has been discussed in conjunction with **Figure 9.20**, but could range, for transportation priority customers, between zero and perhaps two days; for certain functions, it can be shortened by the availability of emergency generators. **L** is essentially the time to bring the pumps into place, ready for operation; with proper pre-storm planning it could be almost zero; if no preparations at all have been made, it may easily take a week to get so many pumps from across the nation to New York, especially if adjacent coastal communities have similar demands. **P** and **A** have been discussed above, and **R**, repair time, is highly uncertain and system-specific.

If, for instance in the case of subways, repairs need to be performed on existing relay, signal, and switching gear of older vintage (such as electric controls, pumps, and ventilation systems, which may need to be disassembled, cleaned, dried, reassembled, installed, and operationally tested because replacement by new spares are not an option), **R** may contribute the largest term and associated uncertainty in equation 2. For a new transport system, or a much simpler road tunnel, the **R** time may be shorter than, or comparable to **P**.

All numbers in column 3 are elevations in feet. All numbers in columns 4–6 are time estimates in days. Rows 1–4 are region-wide, generic (not structure-specific) estimations of days, i.e., **D, E, L** contributing to the service outage (except L is coupled to a facility by the operator $|>P$ to whether pumping is needed, $P>0$; or is not needed ($P=0$) at any facility listed in Rows 5–27; the $|>P$ operator determines whether L is accounted for when selecting Max{**D,E,L**}. The parentheses {**P,A,R**} in columns 4–6, rows 5–27, contain the days assigned to the delays caused by pumping P, assessing damage A, and repairs R, respectively. The maximum value of the triplet {**P,A,R**} is then added, for each scenario, to the resulting Max{**D,E,L**|P>0} listed in row 4 (for each scenario, columns 3–5; note that the upper bound is listed; for less complicated transport systems lesser values were chosen). This sum is then entered as the bold number T=... in columns 3–5, rows 5–27. This value T constitutes the estimated T90 (days) for each facility and storm surge/sea level rise scenario. Row 30, columns 3–5 list the range of T90 values obtained. These are assigned to T90min and T90max, respectively, as used for economic estimates in this chapter's case study, Appendix C, and Equation 4 therein.

The color code (see **Table 9.5**, footnote) indicates for which coastal storm surge scenario the respective facility becomes flooded (i.e., red for LCE$\leq Z_i$, orange for LCE$\leq Z_i+2$ feet, green LCE$\leq Z_i+4$ feet); or never becomes flooded (dark grey, LCE$>Z_i+4$ feet) for the modeled 100-year storms and sea level rise assumptions. The color scheme signals how readily a system/facility floods, from red as most vulnerable to grey as quite safe with orange and green in between.

Table 9.5 displays the results assuming no adaptation or protective measures are undertaken other than those indicated.

In specific cases, adaptation measures can drastically reduce the vulnerability of the systems and facilities. As such, the outage time and resulting economic impact, including fare/toll revenue losses to a system's operator, can be greatly reduced by taking preventative measures. Such protective measures also would avoid some of the damage and limit repair costs.

Economic Impact of the Vulnerability of New York City's Transportation Systems to Sea Level Rise and Coastal Storm Surges: Case Study Results vs. Losses from Hurricane Katrina

The social and economic impacts of a coastal storm with storm-surge flooding can be significant and in some instances long lasting. This has been vividly demonstrated by the extreme case of the effects of Hurricane Katrina on New Orleans in 2005, which cost in excess of $100 billion in losses, social disruptions, and displacements.

However, there are many differences between this ClimAID 100-year storm case study for the New York City metropolitan area and Hurricane Katrina in New Orleans. Portions of New Orleans are as much as 8 feet permanently below the average current sea level. So, once the levees were breached during Katrina, quasi-permanent flooding prevailed. Virtually all of the New York metropolitan area is above, albeit close to, sea level, with the important exception of some underground portions of the transportation and other infrastructure and of some excavated basement structures. Once the lowest critical elevations and/or the pumping capacities are exceeded by the floodwaters, then the physical circumstances simulate those of any inundated below-sea-level community.

Another difference is that Katrina was a hurricane of Saffir-Simpson category 3. As pointed out earlier, the 100-year storm used in this case study is closer to a non-direct but nearby hit of a hurricane of category 1 to 2.

On the other hand, the asset concentration in the New York City metropolitan region (some outside of New York State) is approaching $3 trillion—much larger than that of New Orleans. About half the assets are in buildings and half in infrastructure of all types. The metropolitan region's gross regional product is in excess of $1.466 trillion per year,[43] corresponding to a daily gross metropolitan product (DGMP) of nearly $4 billion per day.[44]

To assess the economic impact of such a storm on New York City, the ClimAID assessment made a number of assumptions. For example, after such an extreme event it is assumed that electricity and the economy come back not suddenly but gradually. The cost of a storm event depends on how quickly the economic activity can be restored. The analysis considers a range of how long this might take under current conditions and the two sea level scenarios, from a minimum restoration time to a maximum. The cost of a storm event must also consider the physical damage to the infrastructure. (For a complete list of assumptions and how the analysis was conducted, see Appendix C).

The procedure, described in Appendix C, yields a "time-integrated economic loss for the entire metropolitan" region (TIELEM), in dollars. Based on this analysis, the economic losses, due to failure of infrastructure systems in the entire New York City metropolitan region, range from $48 billion (current sea level) to $57 billion (2-foot rise) to $68 billon (4-foot rise). Economic recovery times would range from 1 to 29 days (**Table 9.5**). The results of this economic loss analysis are summarized in **Table 9.7**.

To these time-integrated economic losses (TIELEM), one must add the cost of the direct physical damages resulting from the storm. Then the total costs become even greater (**Table 9.5**). Physical damages alone are valued from $10 billion (current sea level scenario) to $13 billion (2-foot rise) to $16 billion (4-foot rise). For details on how the physical damage losses were derived, see Appendix C. Total losses, including both economic activity and physical damages, range from $58 billion (current), to $70 billion (2-foot rise), to $84 billion (4-foot rise) (**Table 9.8**).

Within these estimates there may be unaccounted for numerous other significant constraints on the ability of the transportation systems to recover from climate change-induced incidents. Such constraints include the age of equipment, the availability of replacement parts/equipment, and the need for these in appropriate quantities. These and other currently unknown and/or not-quantified factors could significantly increase climate change impacts in time, labor, and dollars.

Scenario	T90min (days)	T90max (days)	TIELEM ($Billion)
S1 (current sea level)	1	21	48
S2 (2-foot rise in sea level)	1	25	57
S3 (4-foot rise in sea level)	2	29	68

Note: T90min is the minimum amount of time (number of days) needed for the transportation system to regain 90 percent of its pre-storm functional capacity. T90max is maximum amount of time (number of days) needed for the transportation system to regain 90 percent of its pre-storm functional capacity. TIELEM is the time-integrated economic loss for the entire metropolitan region. 2010 assets and 2010-dollar valuation

Table 9.7 Economic losses for the New York City metropolitan region due to current 1/100 year coastal storms and future 1/100 year storms with 2 and 4 feet sea level rise

Scenario	Combined Economic ($ billion)	Physical Damage ($ billion)	Total Loss ($ billion)
S1 (current sea level)	48	10	$58
S2 (2-foot rise in sea level)	57	13	$70
S3 (4-foot rise in sea level)	68	16	$84

Note: 2010 assets and 2010-dollar valuation

Table 9.8 Combined economic and physical damage losses for the New York City metropolitan region for a 100-year storm surge under current conditions and two sea level rise scenarios

The losses summarized in **Table 9.8** do not include any monetary value for any lives lost. There are several reasons for excluding them: 1) it is very difficult to forecast loss of lives since such losses depend on the quality of storm forecasts, emergency planning, warnings, and readiness of the population to follow evacuation instructions and other behavior; 2) given that the New York City Office of Emergency Management and emergency services in the nearby counties in coordination with the New York State Emergency Management Office have extensive coastal storm evacuation plans in place, the loss of lives should be modest; and 3) it is difficult to assess the value of a human life.

The economic losses of Hurricane Katrina on New Orleans illustrate the significant economic impacts a coastal storm and associated storm surge can have. The economic impacts from the storm surge and sea level rise scenarios analyzed in this case study for the New York City area would be comparable with significant impacts and losses to transportation infrastructure.

Vulnerability and Social Equity

The social and economic effects of a 100-year storm would not be distributed evenly. Certain regions would be more likely to cope and recover quickly, while other regions might suffer to a greater degree and over a longer period of time. In general, underlying differences in patterns of poverty, income, levels of housing ownership, and demographics can give some indication of the resilience of an area. These effects are explored in more detail in the Chapter 5, “Coastal Zones”, case study. This section builds upon that analysis by delving more deeply into the role of transportation access in mediating the effects of a storm along New York City and Long Island, both in the evacuation prior to landfall and during the resulting stages of relief and recovery.

This analysis illustrates existing transport disadvantages and the types of vulnerabilities that could be experienced with a storm event of this magnitude. It is important to note that, compared to other cities across the country, New York City has addressed these issues extensively as part of comprehensive evacuation plans. The New York City Office of Emergency Management and the MTA have incorporated income statistics and private-vehicle access into estimates of people who would need evacuation. Public information on the evacuation plans has been distributed in 11 different languages (Milligan, 2007).

Nevertheless, evacuation planning in the New York metropolitan region is very much a work in progress as it relates to transport-disadvantaged and special-needs populations (TRB, 2008b). To some degree, this is a result of intrinsic difficulties in managing an urban area as complicated as the New York metropolitan area, with three states and numerous agencies. While the Department of Homeland Security has been forthcoming with emergency planning funds, it has been less so for funding regional evacuation plans. These efforts are evolving slowly (TRB, 2008b).

Fully addressing transport disadvantage is also hampered by the structure of existing service delivery and the nature of the evacuation plans. The New York City Office of Emergency Management has conducted basic mapping of special-needs populations and made this information publicly available, but it does not have a complete picture of the location or needs of these populations and the resources available to them (TRB, 2008b). Furthermore, strategies that have worked well in places like Tampa, Florida, such as a special-needs registry, have not been attempted in New York City, largely because of the size and complexity of the city. The dominant strategy, therefore, is communicating preparedness through social networks, community groups, and community emergency-response teams, an approach that will not reach the many special-needs individuals who are isolated from consistent outreach services (Renne et al., 2009). As a last-resort option for those unable to arrange their own transport, the city offers "311" emergency services that would link individuals with the city's paratransport vehicles or, in critical situations, with fire and police. Still, there are lingering concerns that the paratransport fleet may be too small during any large evacuation (Renne et al., 2009) and that private-sector drivers might not report to work (TRB, 2008b). Further complicating the approach, there may be a conflict of priorities as public services (e.g., emergency personnel, buses) could be pulled away from the epicenter of evacuation to serve piecemeal needs.

The following section describes the broad climate change impacts, transport disadvantages, and transport resiliencies that extend along the coast of New York City and Long Island. Based on estimates generated for the ClimAID case study (and for current sea level), 90-percent-recovery times for specific parts of the New York City metropolitan transport system would vary from a few days to almost a month. This range in recovery would condition the relative regional severity of indirect economic impacts of a coastal storm surge. Those populations and areas dependent on less-resilient parts of the transport system would more likely suffer extended periods of lost wages and curtailed commercial operations. Some of those hardest hit by systemic failures would likely include populations dependent on the New York subway and those commuting to Manhattan by rail from New Jersey (via NJ TRANSIT) and Long Island (via LIRR), and the commuters of the northern suburbs relying on Metro-North Railroad (MNR).

In general, populations and regions with diverse and redundant transport options would more easily cope and recover from transport systems failure. Further hardship would confront transport-disadvantaged populations and regions, including communities constrained by geography to limited transport options, low-income households dependent on public transport, and individuals with limited mobility.

A recent study of environmental inequalities in Tampa Bay, Florida, suggests three census variables as proxies for transport disadvantage: households with no car, households with disabled residents, and households with residents 65 years or older (Chakraborty, 2009). The ClimAID analysis examines the distribution of these variables across the 100-year floodplain of New York City and Long Island to evaluate vulnerabilities and equity effects in the case of a 100-year storm. **Table 9.9** presents a regional comparison of these indicators.

	In Floodplain	Out of Floodplain
New York Coastal Zone		
% older than 65	14.3	11.9
% physically disabled, age 16-64	5.2	5.9
% households without a car	16.3	10.1
New York City		
% older than 65	13.1	11.1
% physically disabled, age 16-64	6.8	6.7
% households without a car	20.8	23.2
Long Island		
% older than 65	15.2	13.6
% physically disabled, age 16-64	4.1	4.4
% households without a car	2.4	2.1

Source U.S. Census 2000; authors' calculations

Table 9.9 Characteristics of transport-disadvantaged populations living in census block groups: New York Coastal Zone and the case study area

	In Floodplain	Out of Floodplain
New York Coastal Zone		
total workers using public transport	63,819	1,764250
total workers using public transport – bus	14,989	372,028
New York City		
total workers using public transport	48,943	1,635,907
total workers using public transport – bus	13,473	350,935
Long Island		
total workers using public transport	14,875	128,344
total workers using public transport – bus	1,515	21,094

Source U.S. Census 2000; authors' calculations

Table 9.10 Total workers living in New York Coastal Zone and using public transport as primary means of getting to work

	In Floodplain	Out of Floodplain
New York Coastal Zone		
% workers using public transport	27.8	42.1
% workers using public transport - bus	6.4	8.9
New York City		
% workers using public transport	44.9	52.7
% workers using public transport - bus	11.8	11.5
Long Island		
% workers using public transport	11.8	11.7
% workers using public transport - bus	1.3	1.8

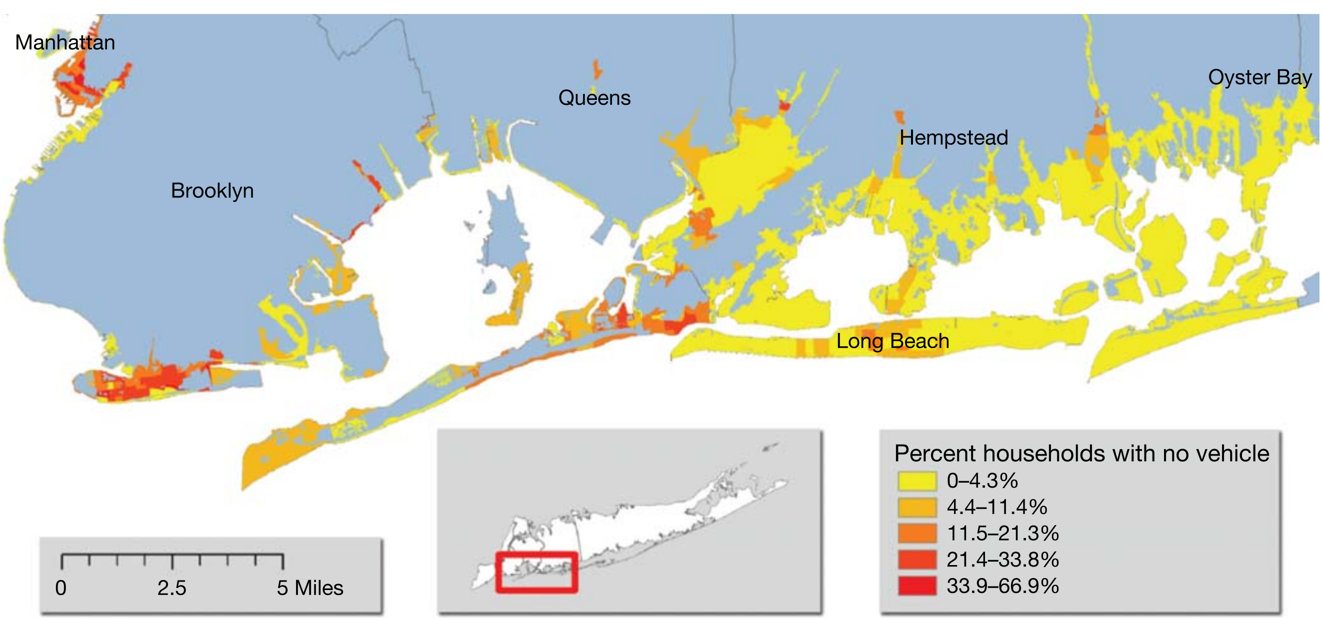
Source U.S. Census 2000; authors' calculations

Table 9.11 Characteristics of transport-disadvantaged populations living in census block groups: New York Coastal Zone

Mirroring the statewide disparity in vehicle ownership between urban and rural areas, car access in ClimAID Region 4 (Chapter 1, "Climate Risks") heavily favors suburban areas of Long Island (**Figure 9.21**). In the urban centers of New York, rates of households with no car are nearly double those for the state as whole, a fact that would condition evacuation before and during a storm. Lower rates of car ownership partly reflect better access to public transportation (such as the New York subway and other trains). On average, working residents in floodplains in New York City are four times more likely than those on Long Island to use public transportation as their primary means of commuting.

In total, nearly 50,000 people live in the floodplain in New York City (**Tables 9.10** and **9.11**).

Evacuation from Long Island, on the other hand, would benefit from the flexibility offered by high vehicle access, but over-reliance could trigger potential delays and disruption from the clogging of highway systems. Despite a more equitable attempt at evacuation for Hurricane Rita following Hurricane Katrina later in 2005, the over-reliance on evacuation by car created a 100-mile long traffic jam, which generated its own vulnerabilities (Litman, 2005). The most critically vulnerable car-dependent populations include those with limited vehicle exit routes for evacuation, such as some populations along choke points in Suffolk County or those in Manhattan who depend on tunnel or bridge access to leave the city.



Source: US Census Data 2000, FEMA FIRM base map, with authors' computations and GIS graphics

Figure 9.21 Variations in access to a vehicle within the 100-year floodplain

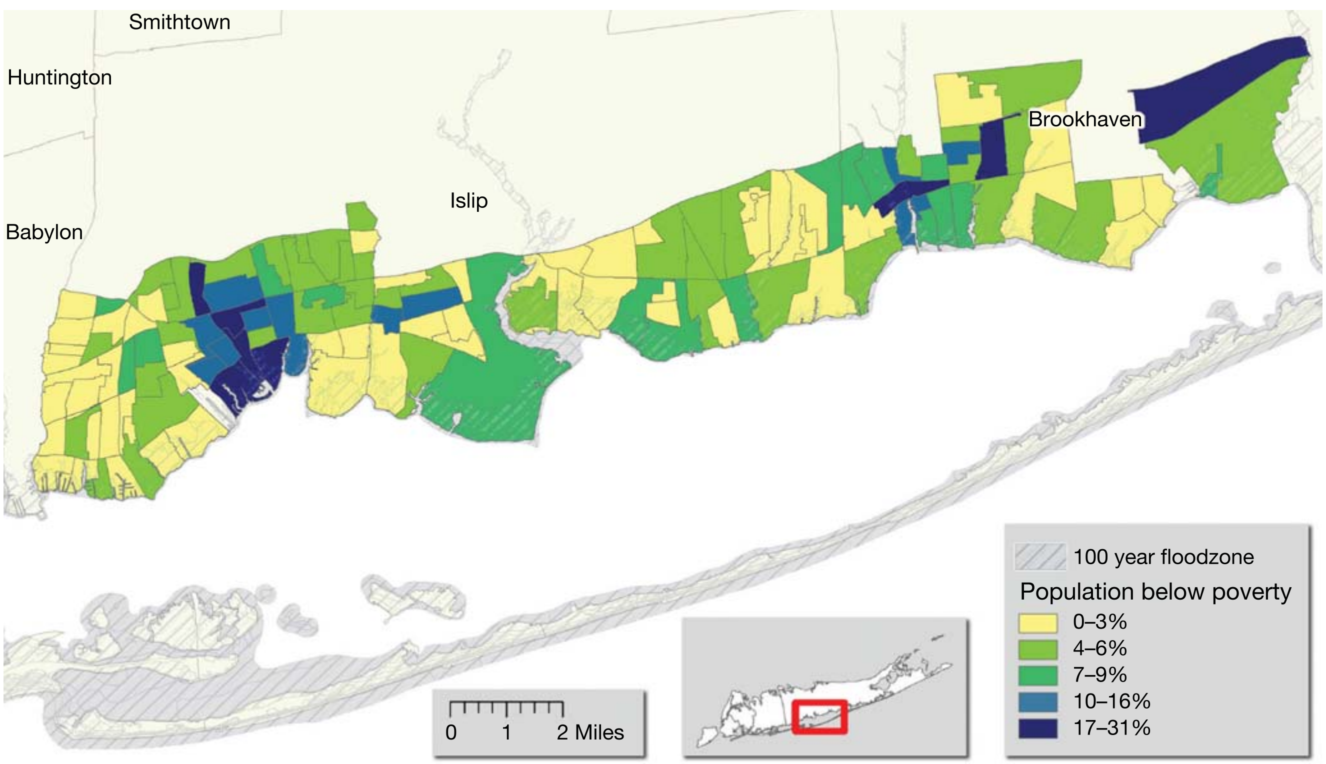
Across census block groups, the percentage of people with access to a car ranges from less than 5 percent to more than 60 percent. Despite generally high rates of car ownership on Long Island, small pockets of low ownership are interspersed largely within Nassau County. A look at the demographic and socioeconomic makeup of a few of these census block groups underscores that car ownership is partly a function of underlying socioeconomic conditions. For example, a few such areas in Hempstead also have higher rates of poverty and lower average educational attainment compared to regional means. These conditions would act together as a group of stresses during a storm event, reinforcing the vulnerability of a person with no car. Put simply, not having vehicle access is a problem for anyone when it is time to prepare for a storm or evacuate, but if that person is elderly with existing mobility challenges or is living below the poverty line as a single mother with two children, then having no car can have a multiplier effect.

The mapping analysis builds on the basic methods used by New York City and Long Island transportation agencies as part of their compliance with requirements set out by Federal Executive Order 12898 on Environmental Justice. For example, the New York Metropolitan Transportation Council identifies the communities in **Table 9.12** as "communities of concern" on Long Island based on socioeconomic and racial status.

Social Justice and Adaptation

Securing transport systems for regional connectivity and mass commuter patterns are critical foci of hazards and adaptation planning. At the same time, successfully integrating equity into system-wide adaptations will require taking seriously the wide range of transport capacities mentioned in the previous section, including constraints on physical mobility, limited access to transportation options, and localized transport dependencies.

A frequently considered short-term adaptation is the selective "hardening" (i.e., protective measures such as buildings seawalls, raising road beds, and improving drainage) of transport infrastructure, but an important question remains: Hardening for whom? Will certain populations and regions benefit from secured commuting and mobility while others do not? For example, in and around New York City, populations reliant on specific local bus routes for commuting—often lower income—may be at a relative disadvantage



Source: US Census Data 2000, FEMA FIRM, and authors' computations and GIS graphics

Figure 9.22 Clustered poverty along the Long Island coast (Great South Bay)

Nassau County		Suffolk County	
Town	Village/Hamlet	Town	Village/Hamlet
Glen Cove	Glen Cove	Huntington	Huntington Station
Hempstead	East Garden City		Wyandanch
	Uniondale		Wheatley Heights
	Hempstead		N. Amityville
	Roosevelt		Copiague
	Freeport	Islip	Brentwood
	Elmont		Central Islip
	Inwood		Oakdale
	N. Valley Stream	Islip/Brookhaven	Holbrook
	Valley Stream		Holtsville
North Hempstead	New Cassel	Brookhaven	Patchogue
	Westbury		Stony Brook
Oyster Bay	East Massapequa		Centereach
			Selden
			Coram
			Middle Island

Source: NYMTC 2007

Table 9.12 Environmental justice communities of concern on Long Island

if hardening infrastructure is aimed at the short-term protection of arterial commuter rail lines and regional business connectivity to Manhattan. In New York City, bus commuters constitute 11.8 percent of the population in the floodplain (**Table 9.11**), many of whom are commuting within boroughs. On the other hand, bus systems are less vulnerable to storm surge flooding, since they generally can resume their function shortly after the floods retreat. Fixed rail lines, and especially those depending on tunnels, may require much longer recovery times after a storm as described in this case study.

A longer-term adaptation strategy is managed retreat, consisting of coastal buyout and relocations. Low-income regions and populations could be particularly sensitive to indirect effects of such interventions. For example, a protracted program could incrementally change land use and regional perception in ways that devalue communities prior to buyouts. There is also a risk that social support and monetary compensation are inadequate for successfully moving and reintegrating migrants. As **Figure 9.22** suggests, wealth and poverty tend to cluster in localized areas along the coast of Long Island and New York City. This uneven distribution would condition the response and sensitivity of different communities to a buyout program. Transport-specific issues include the exacerbation of spatial mismatches between jobs and housing centers as migrants put new pressures on local job and housing markets. This is a recurring challenge for planners on Long Island, where New York City's gravitational pull on the transport system exacerbates a mobility gap for those trying to commute north to south across the island rather than east to west (see, for example, http://www.longislandindex.org/).

Coastal Storm Surge Adaptation Options, Strategies, and Policy Implications

Options and time scales for adaptation measures vary over the short, medium, and long terms:

1) *Short-term Measures (over the next 5 to 20 years)*
   - Short-term measures (individual floodgates, berms, local levees, pumps, etc.) can be effective for a few decades for high-to-moderate probability events, i.e., surges with annual probabilities with low-to-moderate recurrence periods of 100 years or less (storms up to or weaker than the 100-year storm). These "concrete and steel" or "hard" engineering measures may be preceded by or combined with interim measures that improve a system's operational resiliency (e.g., those mentioned for the Lincoln and Holland Tunnel ventilation shaft doors, see footnotes to **Table 9.5** and **Table 9.4**). MTA NYCT is currently undertaking one such short-term measure by raising floodwalls at its 148th Street Yard along the Harlem River. This measure avoids the repeat of flooding already experienced in the past.

2) *Medium-term Engineering Hard Measures (over the next 30 to 100 years)*
   - System or site-specific (i.e., each station, rail track segment, substation, etc.) measures are needed to protect each site individually, such as by raising some structures or track segments.
   - Region-wide protective measures, such as constructing estuary-wide storm barriers, have been proposed (Aerts et al., 2009). These have been discussed in NPCC 2010.

3) *Long-term Sustainable Strategies (any time from now to beyond 100 years)*
   - Long-term measures include changing land use and providing more retreat options. These measures can be combined with the short- and

medium-term strategies indicated above. When sea level rise combined with coastal storm surges exceeds the design elevations of barriers and levees, these long-term strategies require comprehensive, sustainable plans that include time-dependent decision paths and "exit strategies."

To determine the optimal climate change adaptation for the transportation system in the coastal zone of New York State with the highest benefit-cost ratios, the time-dependent assessments listed below for current and projected future conditions need to be performed. Depending on the structure or system, these assessments may need to be projected out 100 or 150 years:

- Make probabilistic time- and sea level rise-dependent coastal storm surge hazard projections on a regular basis.
- Conduct a vulnerability assessment of transportation infrastructure systems given the hazard projections.
- Develop time-dependent transportation infrastructure asset-value estimation methodology and databases.
- Combine the above three items into regular time-dependent risk (loss) assessments.
- Assess costs and benefits of various adaptation options as a function of time.
- Conduct policy and finance assessments.
- Develop decision making and implementation strategies based on all of the items above.

Case Study Knowledge Gaps

The following major knowledge gaps for the transportation sector of the New York State Coastal Zone have been identified from the case study:

- High-resolution digital elevation models for terrains with infrastructure
- The as-built infrastructure elevations, geometry and volumes of the above- and below-grade structures, openings, hydrodynamics, flow rates, filling times
- Vulnerabilities (fragility curves) for coastal storm surge hazards for items listed in the prior bullet, especially when saltwater comes in contact with sensitive equipment
- Realistic estimation techniques for outage times, costs, and reduced losses versus benefits from adaptation measures
- Better economic models for the relationship of transport system outage to over-all economic losses
- Institutional and policy issues related to: How to foster strategic long-term planning at agencies? What is the legal/regulatory framework, and how can professional codes (engineering codes, FEMA's National Flood Insurance Program regulations, enforcement, etc.) be updated to take projected sea level rise and increased coastal storm damage into account ?

Case Study Conclusions

This detailed case study of 100-year coastal storm surges for current sea level and two sea level rise scenarios has provided insights into the technical, economic, and social consequences of climate change. They demonstrate, by example, the potential severity of climate change impacts on the state's transportation sector. Timing of adaptation paths, institutional transformations needed to embed adaptation measures into decision making, and allocation of funding present serious challenges. There is a broad range of policy options and measures that can be implemented to avoid future climate-related losses and to provide the state with a sustainable, climate-resilient transportation system.

Hazards, risks, and potential future losses from climate change—and especially sea level rise—to the region's transportation systems and general economy are increasing steadily. Costs, when annualized, may amount initially to an average of only about $1 billion per year over the next decade. By the end of the century, these costs will probably rise to tens of billions of dollars per year, on average. Note that these are long-term annualized averages. Individual storms may cost much more, as described above in the ClimAID scenario analysis.

Benefits versus Costs

Several thorough studies have shown, based on empirical data from the last 30 years, that there is an approximate 4-to-1 benefit-to-cost ratio of investing in protective measures to keep losses from disasters low

(MMC, 2005; CBO, 2007; GAO, 2007). If the 4-to-1 benefit-cost ratio for protective and other mitigation actions applies, then up to one-quarter of the expected annual losses should be invested every year. This approach provides rough guidance for the needed investments towards protective measures that can be considered cost-beneficial, if based on sound engineering and planning.

Based on the loss estimates given in **Table 9.8** for the 100-year storm,[45] this implies that hundreds of million dollars per year initially may be needed for protective adaptation measures, rising to billions per year at latest by mid-century. Such investment be needed by mid-century because of the long lead-times for infrastructure projects, and to ensure that adequate protections are in place before the end of century. Institutions must plan for the long term, sometimes as much as one to two centuries into the future, for instance when considering right-of-way and land-use decisions, especially in coastal areas. Such major climate change adaptation measures need to be integrated into the overall infrastructure upgrade and rejuvenation projects during the coming decades.

It is important to act before systems become inundated and damaged beyond easy repair.

Long-term Sea Level Rise

Decision-makers need to engage with scientists to monitor the Greenland Icesheet and the West Antarctic Ice Shield, which have the potential to contribute multiple feet to sea level rise this century. These impacts may need to be considered even when planning short- or medium-term adaptation strategies, in order to ensure their long-term sustainability.

In Europe, researchers have analyzed what to do under a scenario in which sea level rose by about 15 feet over the course of one century. The desktop exercise, named *Atlantis* (Tol et al., 2005), has been performed for three regions in Europe. The study areas included the Thames Estuary/London, the Rhine Delta/Netherlands/Rotterdam, and the Rhone Delta/South France. While the hypothetical scenario has a low probability, its high consequences put the larger societal issues into perspective for what, in reality, may turn out to be incremental solutions that are socially acceptable.

Indicators and Monitoring

The establishment of a climate indicators and monitoring network will enable the tracking of climate change science and impacts. Recording the changes in the physical climate (sea level rise), climate change impacts (flood events), and adaptation actions can provide critical information to decision-makers (Jacob et al., 2010).

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Appendix A. Stakeholder Interactions

Stakeholders of the New York State Transportation Sector cannot be easily differentiated by modes of transportation (air, water, ground), but are more readily described by their public, semi-public, and private institutional status, with considerable overlap across modes in these three classes of ownership.

The New York State Department of Transportation (NYSDOT) has the broadest statewide oversight function, in close coordination with U.S. federal transportation programs and guidelines. On a regional basis, government-established transportation authorities with a quasi-corporate administrative structure have the mandate to serve the public's transportation needs (examples include Metropolitan Transportation Authority (MTA), Port Authority of New York and New Jersey (Port Authority), New York State Thruway Authority, New York State Bridge Authority, etc.). In addition, there are many private transportation operators, including airlines, ferries, maritime and river barge operators, bus companies, rail freight companies, individual trucking operators and—last but not least—private truck and car owners, cyclists, and pedestrians. The ClimAID stakeholder process focused primarily on ground transportation, and on the public and semi-public transportation sector. Stakeholders of the ClimAID transportation sector thus included NYSDOT, MTA, the Port Authority of New York/New Jersey, Amtrak, CSX, New Jersey Transit, and others.

Stakeholders were invited to ClimAID meetings at the beginning of the project. Survey forms were sent to stakeholders early in the project asking for information related to a self-assessment of their vulnerabilities to climate change. In the New York City metropolitan area, ClimAID greatly benefited from the process that the NYC Climate Change Adaptation Task Force had undertaken to collect climate change vulnerability information and systematically order it in a risk matrix for importance/severity and adaptation feasibility (Adam Freed, personal communication, 2009; NPCC, 2010). The ClimAID stakeholder process also benefited greatly from close cooperation and coordination with the New York State Sea Level Rise Task Force on all matters related to sea level rise.

ClimAID transportation focus group meetings were held with individual agencies (MTA, the Port Authority of New York/New Jersey, and others) and by numerous conference-call working sessions to clarify survey questions and address security issues. The focus was previously on detailed technical issues regarding climate change vulnerabilities and protective measures.

Contributions to the chapter topics were solicited from the stakeholders. A total of at least three drafts of the chapter at various stages, and for some stakeholders several more, were provided for comment and input. Numerous comments, corrections, and improvements were received. This extensive iterative process led to the final version, which incorporated as many of these improvements as possible. But the responsibility for the final version rests with the ClimAID transportation sector research team.

Stakeholder Participants

- Amtrak
- CSX
- Federal Highway Administration
- Florida State University
- Long Island Railroad
- Metropolitan Transportation Authority
- New Jersey Transit
- New York City Office of Emergency Management
- New York City Office of Long-Term Planning and Sustainability
- New York City Transit
- New York State Department of Environmental Conservation
- New York State Department of Transportation
- New York State Office of Emergency Management
- New York University
- Port Authority of New York and New Jersey
- US Department of Homeland Security
- US Geological Survey

Appendix B. Method of Computation of Area-Weighted Average Flood Elevations for Nine Distinct Waterways in New York City

As stated in the main body of this chapter, the 2- and 4-foot sea level rise values are similar to the rapid ice-melt sea level rise scenario forecasts for the 2050s (2 feet) and 2080s (4 feet), described in Chapter 1, "Climate Risks," and by the New York City Panel on Climate Change (NPCC, 2010). Both sources provide more highly resolved sea level rise ranges: 19 to 29 inches by the 2050s and 41 to 59 inches by the 2080s, with central values of 24 inches and 50 inches. Within the integer-foot resolution (rounded whole number values) adopted for this case study, the investigators have approximated these two measures as 2 feet (2050s) and 4 feet (2080s). When in the course of this case study any maps or tables refer to 2-foot and 4-foot sea level rise, then this represents an approximation of the more precise sea level rise estimates and their range of uncertainties as given originally in the New York City Panel on Climate Change study for the rapid ice-melt model.

To analyze the risk that flooding poses to transportation infrastructure, the elevations of the structures relative to the elevation of the floodwaters according to FEMA's 100-year flood maps are analyzed. New flood zones that account for the anticipated 2- and 4-foot sea level rise are then also analyzed with respect to their impact on transportation structures.

When the effects of flooding on extended transportation networks are analyzed, then the relative elevation of the floodwaters to the transport system's critical elevations must be measured at many locations along the transport network's geographical extent. To achieve this task within the timeframe and resources available for this study, the ClimAID team used an approximation. FEMA's Flood Insurance Rate Maps (FIRMs) provide 100-year base flood elevations at a finite number of points along a waterway. The actual base flood elevations vary slightly from location to location within the flood zones mapped by FEMA that are shown, without alteration, as the red zones in **Figure 9.7**. The variations in flood elevations occur for hydrodynamic reasons related to bathymetry, topography, wave and wind exposure, etc.

When adding 2 and 4 feet of sea level rise, new flood zones of an indeterminate shape on their landward side result. That shape does not exactly follow terrain contours of constant elevations, just as the flood zone boundaries of FEMA's 100-year base flood elevations cross contours of constant elevations, according to hydrodynamic factors. To minimize the effort to determine the relative height of a transportation system versus flood elevations that vary slightly from location to location, the entire New York City water and land area was subdivided into nine waterways, based on their tidal and coastal storm surge characteristics (**Figure 9.8**).

Using the discrete FEMA-provided 100-year base flood elevation control points along the shores of each waterway, averaged base flood elevation control heights were computed for each of the nine zones. The arithmetic mean (simple average; **Table 9.13**, column 3) of the base flood elevation control points for each zone was, however, *not* applied. Instead, an area-weighted mean (Z_i, or area-weighted base flood elevation, column 4) was used. The weights were assigned proportional to the areas that the control points represent along the shorelines of each waterway. This weighting minimizes the undue influence of shore segments with unusually high density of control points that may skew the average base flood elevation for each waterway. **Table 9.13** (column 6) shows the number of control points for each zone (waterway) and the standard deviation (column 5) around the weighted mean for each area-weighted mean value.

Note that the original base flood elevations from FEMA's Flood Insurance Rate Maps are generally (at least for New York) referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929). The investigators, however, chose the new, averaged sea level rise-dependent flood zone elevations to reference to the more recent, and now generally more commonly used, North American Vertical Datum (NAVD 1988). Note that in contrast to FEMA maps in New York, FEMA maps for New Jersey use the NAVD 1988 datum. A constant difference of 1.1 feet between the two datums was used throughout the New York City area such that the numerical elevations above the two vertical datums relate to each other by Equation 3:

Equation 3. Elevation(ft) above NAVD'88 = Elevation(ft) above NGVD'29 - 1.1 ft

The so-derived, area-weighted average base flood elevations or area-weighted average (in the NAVD'88 reference frame) are rounded to the nearest integer foot for assessing the flood and sea level rise impact on transport in the region.

Once the area-weighted and integer-rounded average base flood elevations (or area-weighted averages) were obtained for the nine waterways, the 2- and 4-foot sea level rise estimates were added to these values. This allows the elevations of transport structures to be easily compared to the flood zone elevations.

In the regions outside New York City, including Long Island (Nassau and Suffolk counties), Westchester County, and the Lower Hudson Valley, much cruder approaches were used for a number of reasons. First, no high-resolution digital elevation model with a 1-foot vertical resolution was uniformly available for these regions outside of New York City. Additionally, for these areas, the lowest critical elevations are not known for many of the transportation systems and related structures as well as they are known within New York City. The New York City estimates were largely obtained from the

Zone (i)	Waterway	Rounded, Average Base Flood Elevation (feet) NGVD 88	Rounded, Area-Weighted Average Base Flood Elevation in NGVD 88, Z_i (feet)	Standard Deviation (feet)	Number of Points on FEMA Flood Map per Zone (n)	Relevant Boroughs
1	Long Island Sound	14	14	1.45	31	Bx, Q
2	East River	13	11	1.06	53	Bx, Q, M
3	Harlem River	9	9	1	3	Bx, M
4	Hudson River	8	8	0.71	2	Bx, M
5	Inner harbor	9	9	0.97	13	M, Bk, SI, (Q)
5A	Kill Van Kull	8	8	0.63	6	SI
6	Outer Harbor	10	10	1.20	48	SI, Bk
7	Jamaica Bay	7	8	0.72	32	Bk, Q
8	Rockaway (Atlantic and Jamaica Bay)	8	9	1.13	22	Q

Note: Bk=Brooklyn, Bx=Bronx, M=Manhattan, Q=Queens, SI=Staten Island

Table 9.13 New York City waterway zones and their rounded average values for obtained area-weighted base flood elevations

Hurricane Transportation Study (USACE, 1995), and the metropolitan east coast (MEC) climate change infrastructure study (Jacob et al., 2000 and 2007).[46]

This lack of elevation information points to the need for accurate, accessible digital elevation models in the storm-surge-prone coastal zones of New York State. These models need vertical resolutions of less than 1 foot. There is also a need for accurate as-built elevations of the transport structures. The digital elevation model resolution is technically achievable with carefully executed remote sensing technology (LIDAR surveys) and careful post-processing after acquiring the raw data. Some coverage with this technology exists in New York State, but needs to be undertaken systematically, at least for all flood-prone zones across the state that are affected by sea level rise and coastal storm surges. The collection of reliable elevations of transport structures in these critical areas is in the best interest of the operating agencies, but needs to be performed in the public interest as part of a concerted statewide flood-risk management plan.

Appendix C. Method to Compute Economic Losses (Appended to Case Study A, 100-Year Coastal Storm Surge with Sea Level Rise)

To estimate the economic losses from the ClimAID case study storm scenario, using the values summarized in **Table 9.5**, these assumptions were made:

- The economic activity is essentially zero from day zero to the lowest value of T90, for each scenario, listed in Row 30 of **Table 9.5**.
- The economic activity recovers gradually (assuming a linear relation) from day T90min to T90max, where the latter is the upper bound of the T90 value (in days) listed in Row 30 of **Table 9.5**, for each scenario.
- The recovery from 90 percent functionality to 100 percent functionality (on day T100) occurs with the same slope as between 0 and 90 percent functionality.

This concept of a gradual recovery of the economy (rather than coming to a total halt and then suddenly jumping back into full gear) is important for fully appreciating how the information in **Table 9.5** is used. TheT90 values in row 30, columns 3, 4, and 5, are not the times by which the economy is assumed to start recovering; these values are intended to mark the times by which the economy has recovered to 90 percent of its pre-disaster level, i.e., they mark the time by which the recovery has come almost to an end, and had made progress for the entire period in the days between T90min and T90max after the onset of the disaster.

All of these assumptions and approximations are highly uncertain, but can be justified by comparing them to the electric grid recovery curve shown in **Figure 9.20**, except the slightly upward convex curve of this figure is replaced with a linear relation. The basic concept is that electricity and economy come back not suddenly but gradually after such an event. Even if some transport modes do not work, commuters may find a way to substitute, work at home, or pay for and/or share a taxi (for caveats, see Vulnerability and Social Justice sections of the case study).

With these assumptions, the time-integrated economic losses for the entire metropolitan region (TIELEM) from the 100-year storm of the case study can be computed by integrating (summing up) over time the gradually (i.e., with time linearly) decreasing daily economic productivity losses from day zero to day T100. Using this concept of decreasing daily losses and increasing recovery of the economy yields Equation 4:

Equation 4: TIELEM = DGMP [T90min + ½ (T90max – T90min) 100/90]

Using the daily gross metropolitan product, DGMP = $4 billion/day and the T90min and T90max values of **Table 9.5** for the three SLR scenarios S1 to S3, yields the TIELEM values summarized in **Table 9.7**.

Forward-Projection of Losses to 2050 and 2090

Note it has been assumed that all three SLR scenarios are applied to the 2010-DGMP. But the three scenarios require time for sea level to rise. The study assumes that the three scenarios occur in S1=2010, and that S2 occurs in the 2050s and S3 before 2090. Therefore, the study must account for what the economic trends for the next 40 and 80 years could be (a) by accounting for inflation and/or discount rates; and (b) by accounting for economic growth, expressed by increasing DGPM and/or increasing asset values. These trends can be formally treated in the same way as compounding interest for an interest rate of **r** % (say for inflation or economic growth rate), while adding a certain *fixed amount* of dollars **p** to every 100 dollars of built assets, say, *at the end of each year* (note that this means a steadily *decreasing percentage* addition of assets, since the dollar amount **p** stays constant while the initial asset value increases by compounding in relation to **r**).

Using, for example, the assumption that scenario S2 occurs around 2050, i.e., 40 years from now, and that scenario S3 occurs 80 years from now; and that for every $1 trillion/year in economic activity, another (constant) $20 billion per year (i.e., **p=2**) is added over the next 40 years or 80 years, respectively, then the multipliers for the S2-TIELEM of $57 billion, and for the S3-TIELEM of $68 billion, respectively, as a function of an effective economic growth rate **r** will be as indicated in **Table 9.14**.

Added to the economic losses (TIELEM) must be the direct *physical damage* **D** ($), incurred by the affected infrastructure during the storm. Since no vulnerability or fragility curves for the transportation systems, nor a realistic aggregate asset value of the transportation infrastructure, are known with any degree of accuracy or confidence at this time, proxies are used with uncertain validity. For a first-order approximation, we make the following working assumptions for estimating the direct damage **D** for this case study, and using several different approaches:

a) The regional combined transportation assets are on the order of $1 trillion (2010 dollars). The physical damage rates, based on typical flood scenario computation with the tool HAZUS-MH, are taken to be on the order on the order of 1.00, 1.25, and 1.50 percent of the asset values, respectively, for the three scenarios S1 to S3, respectively. This yields direct physical damage losses of **D=$10, $12.5, and $15 billion** (for 2010 assets) for the three scenarios, assuming they all were to occur in the year 2010. Since they do not, multipliers shown in **Table 9.14** would apply for S2 and S3 occurring in 2050 and before 2090, respectively, and assuming all other conditions would apply when the **Table 9.14** multipliers were computed (i.e., constant **p=2** or **$20 billion** annual infrastructure asset additions to the initial [2010] $1 trillion assets).

b) Based on limited observations, a finding is that losses for infrastructure assets during natural disasters in urban settings are typically of the same order of magnitude as for the building-related losses in the same area (e.g., Jacob et al., 2000). NYSEMO periodically computes losses (using the FEMA-sponsored HAZUS-MH software) associated with various storm scenarios for emergency exercises. One of these is a storm scenario in which a category 3 hurricane named "Eli" traverses Long Island making landfall near the boundary between Nassau and Suffolk county (D. O'Brien, NYSEMO, personal communication, October 2009). While this scenario is excessive for Nassau and Suffolk, it produced wind speeds and coastal storm surges for the five NYC boroughs and for Westchester County that are comparable to our 100-year storm scenarios. The building-related losses from the storm surge flooding in the five boroughs amounted to slightly over $20 billion, while in Westchester County it was just below $0.6 billion (for comparison, the wind damage in the five boroughs was only about $110 million and in Westchester $16 million). Moreover, an interesting observation is that the ratio of storm-surge flood- to wind-related losses was 3 to 1 for all counties in New York State affected by scenario "Eli."

Effective Economic Growth Rate *r* (%/year)	0	1.5	1.75	2.0
S2-TIELEM Multiplier for 40 Years:	1.8	2.91	3.16	3.44
S3-TIELEM Multiplier for 80 Years:	2.6	6.39	7.50	8.83

Table 9.14 Multipliers for 40- and 80-year time horizons as a function of growth rate *r* when p=2

If the results from the two approaches are combined, the conclusion is that the physical losses for all infrastructure systems for the entire scenario region due to coastal storm surge flooding is on the order of a few tens of billions of dollars; i.e., in the range of $10 to $20 billion. How much of it is attributable to damage to transportation versus other infrastructure? While at the moment there are no hard data to affirm this, the ClimAID Transportation study suggests, largely because so much of the transportation infrastructure assets are located at or below sea level and are therefore the most vulnerable, that at least half and perhaps as much as three-quarters of this total amount is attributable to damage to the transportation infrastructure.

If the physical damage and the economic losses are compared from the scenario event that are, directly or indirectly by its effect on the general economy, attributable to losses of functionality of the transportation infrastructure, then first-order approximation estimates of total losses from the three storm scenarios (all in 2010 dollars and for 2010 assets) can be obtained and are summarized in **Table 9.5** of the case study.

When reviewing these estimates, the ClimAID team again caution (as stated in the Case Study, in the paragraphs near equation 2) that there may be numerous other significant constraints on the ability of the transportation systems to recover from climate change-induced incidents. Such may include, for example, the age of equipment, the availability of replacement parts/equipment, and the need for such in appropriate quantities. These and other currently unknown and/or not quantified factors could significantly increase climate change impacts in time, labor, and dollars.

Note that **Table 9.14** multipliers for the losses associated with the scenarios S2 and S3 are applicable throughout to modify all losses; they transform them from their current 2010 time base to what they may be during the 2050s and the end-of-2080s, respectively, for the different economic projections and other assumptions stated.

[1] http://www.bts.gov/publications/freight_shipments_in_america/html/table_03.html.
[2] https://www.nysdot.gov/about-nysdot/history/past-present.
[3] https://www.nysdot.gov/about-nysdot/responsibilities-and-functions.
[4] https://www.nysdot.gov/about-nysdot/history/past-present.
[5] http://www.nysba.state.ny.us/Index.html.
[6] http://www.countyhwys.org/.
[7] https://www.nysdot.gov/divisions/operating/opdm/passenger-rail/freight-rail-service-in-new-york-state.
[8] http://www.aar.org/Homepage.aspx and foot note above.
[9] Class I railroads are those with operating revenue of at least $272 million in 2002. http://www.nationalatlas.gov/articles/transportation/a_freightrr.html.
[10] http://www.guardian.co.uk/environment/2006/nov/01/society.climatechange/print.
[11] MEC infrastructure report (Jacob et al. 2000, 2001); FEMA FIRM flood zone maps; and http://www2.sunysuffolk.edu/mandias/38hurricane/.
[12] MEC infrastructure report (Jacob et al. 2000, 2001); NPCC-CRI (2010).
[13] See Chapter 1: “Climate Risks”; and New York City Panel on Climate Change “Climate Risk Information” (2010).
[14] TRB (2008a).
[15] CCSP, 2008a: Gulf Coast Study, Phase I. http://www.climatescience.gov/Library/sap/sap4-7/final-report/.
[16] USACE, 1995; MEC, 2001; and MTA, 2007. The 08/08/07 Storm Report; NPCC, 2009, 2010 and NYCCATF (in preparation).
[17] CCSP, 2008b; http://www.pogo.org/investigations/contract-oversight/katrina/katrina-gao.html.
[18] DeGaetano 2000; Jones and Mulherin 1998.
[19] The Tappan Zee Bridge is expected to be replaced with a new structure, but timing is uncertain.
[20] Stedinger (2010).
[21] TRB (2008a).

[22] The New York State Constitution provides for democratically elected legislative bodies for counties, cities, towns and villages. These legislative bodies are granted the power to enact local laws as needed in order to provide services to their citizens and fulfill their various obligations.

[23] E.g., for MTA see Jacob et al. 2009; Jacob, 2009; NYS SLRTF, 2010; NYC CCATF, 2010; NPCC-CRI, 2009; NYS CAC, 2010; and stakeholder cooperation with this ClimAID project.

[24] http://www.dec.ny.gov/energy/45202.html.

[25] http://www.nyc.gov/html/oem/html/hazards/storms_hurricaneevac.shtml.

[26] *New York Times*, January 28, 2010: "S.E.C. Adds Climate Risk to Disclosure List" http://www.nytimes.com/2010/01/28/business/28sec.html?sq=sec&st=cse&scp=2&pagewanted=p.

[27] http://www.fta.dot.gov/about/offices/about_FTA_927.html#Mission and file:///Downloads/Post%209_11regional_offices_4154.html.

[28] http://www.gothamgazette.com/graphics/2008/04/DotDensityLowIncomeCommute.jpg.

[29] For a purely random occurrence of storms in time, statistics indicate that the probability that a 100-year storm does occur within the 100-year time period is only 63 percent. This is because the 100-year period is an average; thus, there are periods between such storm events that are longer than 100 years. These longer periods make up for occasional shorter recurrence intervals.

[30] Based on the Poisson Distribution, the probability for an event with average recurrence period T to occur in the time interval t is: p = 1 - e^-(t/T). When t equals T, in this case 100 years, the result turns out to be ~63%.

[31] The technical term of the average flood elevations for the waterways is: "area-weighted base flood elevations (AW BFE). These are later labeled, for simplicity, the Z_i values. For details and listing of the Z_i values in Table 9.13, see Appendix B.

[32] More could be added when maps of Long Island (Suffolk and Nassau County) for base flood elevations (BFE) of 1% per year and 2 and 4-ft sea level rise become available.

[33] The numbers in this figure were derived using a standard GIS intersection operation applied to the New York City street grid and to the three flood zones shown in Figure 9.7.

[34] A nearly complete and more detailed listing of lowest critical elevations of transportation systems in the New York City metropolitan region can be found in USACE (1995), with the caveats that (i) the lowest critical elevations in that reference are given with respect to NGVD, 1929; and (ii) that some modifications to structures or the terrain may have been made since the 1995 report was issued. Where we provide new information not contained in USACE (1995), the source is indicated where identifiable.

[35] MTA, 2006, courtesy A. Cabrera; communication of December 2009.

[36] The Port Authority has an emergency operational plan for Holland and Lincoln Tunnel and for part of its PATH system that will be activated prior to the arrival of a storm. LCE without such measures would be lower (e.g., Holland Tunnel vent shaft: LCE=7.6 feet; and Lincoln Tunnel vent shaft: LCE=10.6 feet).

[37] The ARC project was put on halt in 2010 to explore less costly options.

[38] Each step in this procedure is associated with large uncertainties. The procedure outlined here is site- and system-dependent, especially in the absence of a complete engineering risk and vulnerability assessment. Such an assessment is urgently needed to perform this task rigorously. The stakeholders provided physical data regarding tunnel volumes and pumping capacity of the most essential transport systems, but were unable to provide estimates of system vulnerability, repair, and restoration times and/or associated costs because there are too many unknown variables. Another large uncertainty is whether grid power will remain uninterrupted and, if interrupted, how long it will take power providers to restore it.

[39] ClimAID uses the hydraulic calculations for estimating the total floodwater volume in the tunnels.

[40] These numbers are preliminary and may change subject to more detailed engineering analyses.

[41] In contrast, the pumps installed in the NYCT subway tunnels are of older vintage and their purpose is not pumping out a flooded tunnel but draining the tunnels under normal operational conditions. NYCT's more than 750 pumps in 300 pump stations drain about 8 to 13 million gallons of water per day from the subway system, depending on whether it is a dry or wet day. Using 13 million gallons per day and 750 pumps yields 17,000 gallons/pump/day or just 12 gallons per pump per minute. If the total available pumping capacity after the scenario storm were 17,000 gallons per day (though the actual capacity is higher), it would take nearly 80 days to drain the system. However, not all of the 750 pumps are installed in the sections that would be flooded and, therefore, the process could take even longer. Note that the 12 gallons per minute value does not constitute the pumping capacity available during an extreme event. It is the pumping capacity used during a typical rainy day.

[42] If N is the number of pumps working in parallel at any given time, then the time required would be 1 week x (100/N).

[43] Based on Price Waterhouse Cooper (PWC) data for 2008.

[44] This daily gross regional product for the metropolitan region (DGMP), when used with the outage times listed in Table 9.5, allows the study to estimate the order of magnitude of the economic impact of outages. While the focus of this chapter is on transportation, the highly simplified assumption is used that the economic productivity is a direct function of the operational functionality of the transportation sector. In reality it reflects the functionality of all types of infrastructure (electricity, gas, water, waste, communication, etc.). But because most of these systems are so tightly coupled, the time estimates for transportation (Table 9.5) are, to a first-order approximation, a seemingly rational choice for a proxy for the functioning of all economic activity.

[45] And forward-projected to 2050 and 2090 by the multipliers of Table 9.14 in Appendix C.

[46] More could be added when maps of Long Island (Suffolk and Nassau County) for BFE of 1% per year and 2 and 4-ft sea level rise will become available.

Chapter 10

Telecommunications

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Contents

Introduction

The telecommunications and broadcasting industries are vital elements of New York State's economy. Their combined direct economic contributions to the state's gross domestic product are on the order of $44 billion.[1] Telecommunications capacity and reliability are essential to the effective functioning of global commerce and of the state's main economic drivers, including the finance, insurance, information, entertainment, health, education, transportation, tourism, and service-based industries. It is essential to the daily life of every business, farmer, and citizen across the state, from rural to urban regions, and is especially vital during emergencies. Reduction in communication capacity for an extended period results in commercial and economic losses. This is a critical concern especially in the financial-service markets concentrated in and around the New York City area (The New York City Partnership, 1990).

The communications industry, perhaps more than any other sector, has undergone and continues to undergo a perpetual rapid technological revolution. It has experienced major deregulation and institutional diversification and functions in a state of fierce internal competition. In large part due to rapid technological changes, the planning horizons and lifespans for much of its infrastructure are at best on the order of a decade. This is a very short time horizon relative to the significant climate changes taking place over the scale of multiple decades to centuries. It is also short compared to that for other sectors, for example the public transportation sector, in which some rights of way, bridges, and tunnels have useful lifespans of 100 years or more. That is not to say that some parts of the communication infrastructure cannot be quite old. There are oilpaper-wrapped copper cables hung from poles or in the ground in some places, including New York City, many of which are older than 50 years.

The rapid technological turnover of communication infrastructure versus the pace of climate change gives rise to several inferences and issues:

In the context of the industry's vulnerability to weather and climate, it is essential to focus on its present vulnerability and to ensure its resilience vis-à-vis extreme weather events (and power failures) to provide the highest possible standard for continuity and uninterrupted service under extreme conditions. This, however, depends on the extent to which the market is willing to pay for such reliability and/or the extent to which the State and society at large demand and support higher reliability, including resilience to extreme events. The key questions are: What is the tolerable balance between reliability and cost? And who will bear the costs?

If service reliability and continuity are achievable at an acceptable cost for current weather extremes and if service disruptions can be better decoupled from electric grid power failures, there is good reason to expect that the industry could maintain high reliability vis-à-vis the additional hazards caused by climate change and be able to adapt to such changes with the help of new technologies.

Therefore, unlike many of the other sectors in the ClimAID report, addressing future climate change is arguably less important than addressing the communication industry's vulnerability to the current climate extremes. Additional hazards are expected from climate change in the sense that the frequency and severity of some extreme events are more likely to increase than not. Such events include excessive wind and lake effect snow in the coming decades, bringing down power and communication lines and even some wireless facilities. Some recent events have caused extensive and prolonged service failures with substantial economic and social impacts. Also, where centralized communications infrastructure is located at low elevations near the coast or near rivers and urban flood zones, climate change will pose additional risks that need to be managed comprehensively (see Chapter 5, "Coastal Zones," and Chapter 4, "Water Resources"). The areas at risk of flooding are expected to become larger, increasing the extent of flood zones as well as extending to higher elevations at the currently designated flood zones. In other words, the risk will increase in frequency and severity because of sea level rise and more extreme precipitation events. But these additional climate-change-induced risks are likely to be manageable in the future if currently existing vulnerabilities can be reduced.

There are a number of factors that make reducing vulnerability to extreme climate events challenging, including the following:

- The industry is experiencing strong internal competition and market pressures, which tend to limit redundancy to what dynamic free markets and profit motives are willing to pay for—on both the customer's and service provider's side. Market pressures and the short lifespan of certain telecom technologies result in an industry tendency to replace infrastructure as it becomes damaged, rather than to "harden" existing facilities. This would appear to be a reasonable response to lesser climate threats but it leaves critical components of the network vulnerable to rare but catastrophic events.
- Regulation and related mandatory reporting of service outages are limited and unequal among the different service modes and technologies.
- Customers have little accessible data to make choices based on reliability and built-in redundancy of services; instead, decisions are based largely on convenience, accessibility, marketing, and price.

Reducing current vulnerability while these factors prevail requires balance of policies between providing incentives to and regulation of the telecommunications industry. It can be argued whether it is valid to compare the risk-taking and aversion to regulation that has prevailed in the financial services sector to that of the technology-intensive communications sector. But such a comparative assessment may yield insight into changes to both business and public governance and policies that can guarantee the industry's reliable and continuous delivery of services—even during external shocks from climate-related (and other) extreme events. This could be for the benefit of the sustained economic health of the industry itself as well as of its customers and society at large.

A focus of the telecommunications infrastructure sector—including that of the service providers, the government, and the customer—is on how to ensure that the ongoing introduction of new technologies enhances the reliability and uninterrupted access to services, rather than degrading the reliability of these services. Such a focus is essential both now and in the future, when the impacts from climate change may increase.

The ClimAID telecommunications sector research team interacted with stakeholders from industry and government. A description of this process and the list of stakeholders are contained in Appendix A.

10.1 Sector Description

Telecommunications is one of the fundamental infrastructure systems on which any modern society depends. Its technological sophistication, availability, accessibility, broadband capacity, redundancy, security, and reliability of services for the private and public sectors are telling indicators of a region's economic development and internal social equity.

According to a report by the Federal Communications Commission (2009), the penetration rate for telephone service (land and cell combined) for all New York households was 91.4 percent in 1984, 96.1 percent in 2000 and 93.7 percent in 2008. Nationwide, the penetration rate was 95.2 percent in 2008, 1.5 percent higher than that of New York State. Demographic factors and level of aid to low-income households contribute to the differences in telephone service penetration among states. There is also considerable variance for income groups around the average of 93.7 percent within New York State.

At present, the telecommunications infrastructure sector comprises point-to-point public switched telephone service; networked computer (Internet) services, including voice over Internet protocol (VoIP), 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.

The various domains are highly interconnected, overlapping, and networked. The boundaries between the different media are fluid and shift rapidly, often in concert with changes in technologies. Increasingly, the boundaries between technology providers versus content providers are also in flux.

Ongoing telecommunications innovations include the transition from analog to digital communication, introduction of networked computers, the Internet, broadband services, satellites, fiber optics, and the rapid expansion of wireless communication (including mobile phones and hand-held devices). Fourth-generation (4G) wireless technologies, such as Long Term Evolution (LTE) and WiMAX (Worldwide Interoperability for Microwave Access), provide an advanced IP-based

(Internet protocol) wireless platform for telephony, broadband Internet access, and multimedia services. These are some of the technologies that have transformed telecommunications in the last few decades. Some of these technologies have the potential to expand wireless voice and broadband coverage in unserved and underserved areas of the state.

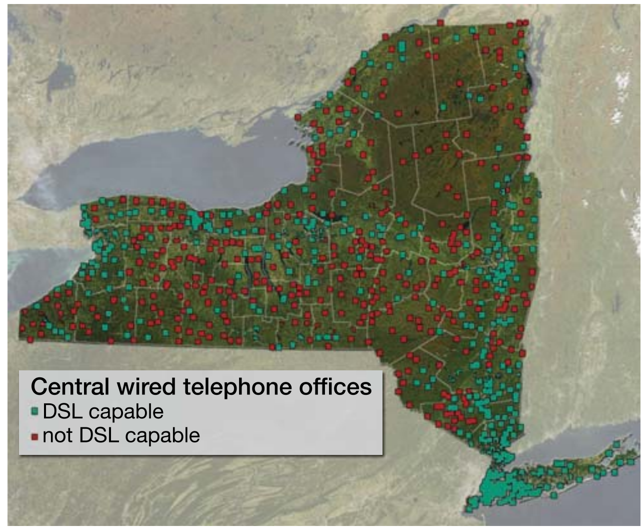
In concert with technology, the institutional landscape of the industry has changed radically. Telecommunications giants, operating as regulated utilities with quasi-monopolies, were broken up in the United States in the mid-1980s to foster competition and innovation. The breakup was paired with considerable deregulation fostering robust intermodal competition followed by more deregulation. Among all types of service infrastructure on which society has come to rely, the telecommunications industry is almost entirely privately owned. It functions more competitively than most basic services that require large infrastructure, including electric power distribution (but not generation), transportation, and water and waste.

10.1.1 Economic Value

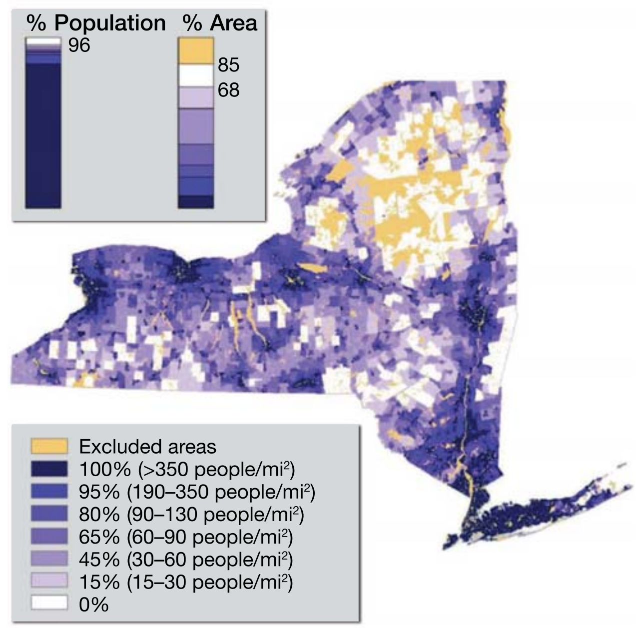
Telecommunications is an important sector in New York State's economy. Its total annual revenues contribute some $20 billion to the state's economy, about 2 percent of New York's entire gross state product of about $1.1 trillion (2007 dollars). Telecommunications is critical to the success of many of New York's largest industries and to many of the industries that will drive the state's growth in the future. New York City's status as a global financial center, for example, is heavily dependent on the capacity and reliability of its telecommunications networks. The New York Clearing House processes as many as 26 million financial transactions per day, at an average value of $1.5 trillion per day, for 1,600 financial institutions in the United States and around the world (NYCEDC et al., 2005).

10.1.2 Non-Climate Stressors

Not all areas of New York State have equal access to broadband wire services. **Figure 10.1** (top) shows a map of central offices (where subscriber lines are connected on a local loop), differentiating between those that are DSL-capable (digital subscriber line) and those that are not. **Figure 10.1** (bottom) shows the cable-modem



Distribution in 2010 of central offices for wired telephone in New York State. Those in green are capable of providing digital subscriber lines (DSL, 2009). Source: http://www.dslreports.com/comap/st/NY; basemap NASA



Source: Redrawn from NYS GIS, 2009

Figure 10.1 Distribution of central offices for landline telephone in New York State, 2010 (top); Predicted cable modem broadband availability, 2009 (bottom)

availability for 2009 as determined by the New York State Office of Cyber Security and Critical Infrastructure Coordination (CSCIC). Note that these are CSCIC's own projections and not based on data provided by service providers.[2]

The Federal Communications Commission (FCC) has oversight of the industry on the federal level, and the New York State Public Service Commission (PSC) exercises oversight on the state level. The stated mission of the PSC is "to ensure safe, secure, and reliable access to electric, gas, steam, telecommunications, and water services for New York State's residential and business consumers, at just and reasonable rates. The Department seeks to stimulate innovation, strategic infrastructure investment, consumer awareness, competitive markets where feasible, and the use of resources in an efficient and environmentally sound manner."[3]

This mission implies that part of the Public Service Commission's role is to see to it that the telecommunications industry adapts to climate change, as the latter poses new challenges to maintaining "safe, secure, and reliable access to telecommunications … at just and reasonable rates." The PSC mission has always included oversight for reliability and continuity of telecommunications services related to natural or man-made events. Climate change adds more urgency to this ongoing mission.

The increased competition that has evolved since diversification and deregulation in the mid-1980s has had consequences for how the industry as a whole (albeit not all of its components) tends to plan and operate. Although redundancies tend to be inefficient most of the time, in emergencies they serve to provide alternative means of communication and much-needed extra capacity. It is in this context that climate change poses new challenges, in addition to those the industry is facing already (e.g., cyber security).

Apart from the commercial communications sector, there are other entities within the state that operate communication systems. For instance, public operators (e.g., police, emergency services, first responders, public safety agencies) communicate internally using mobile and handheld devices, either via trunking systems with multiple channels or via designated channels and reserved bands across the VHF and UHF radio spectrum. In trunking systems, only a small percentage of the users are expected to be active on the network at any given time. In the near future, public safety answering points (PSAPs), which receive and dispatch 911 calls, will need to upgrade their equipment to handle next generation 911 (NG911) calls that accommodate the transmission of wireless information enhanced with text, graphics, and video. Because the county PSAPs in New York operate independently, it is likely that NG911 will not be deployed uniformly across the state.

New York State has made an attempt to build the $2-billion New York State Statewide Wireless Interoperable Communications Network, which was originally commissioned in 2004. This centralized plan was cancelled in its originally designed form in January 2009 because tests showed unreliable performance.[4] The new version of a statewide interoperable network will rely more on existing and planned county and city communications networks in order to achieve operational interagency communications on the local, city, county, state, and federal levels. The difficulties of multiple services not being able to communicate effectively with each other during emergencies has been a long-standing problem, and the new cooperative efforts on the federal, state, and local levels through this state-guided program are aimed at overcoming these problems.[5]

10.2 Climate Hazards

The climate hazards and their expected changes for the various regions of New York State are described in detail in Chapter 1, "Climate Risks." We summarize here briefly some key features of these hazards relevant to the Telecommunications sector. Examples of extreme weather events and their impact on telecommunications are presented in Section 10.3 (Vulnerabilities).

10.2.1 Temperature

ClimAID projections for the number extreme hot days per year show that the number of these events is expected to increase as this century progresses. In addition to more frequent hot days, the frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures above 90°F, are also expected to increase. In contrast, cold temperature extremes, such as the number of days per year with minimum temperatures below 32°F, are projected to become less frequent. The extreme event temperature projections shown in Table 1.8 of Chapter 1 are based on observed data from stations within each climate region. Because the higher latitude zones of each region experience a cooler baseline climate, they will probably experience fewer future heat events than those shown in the tables.

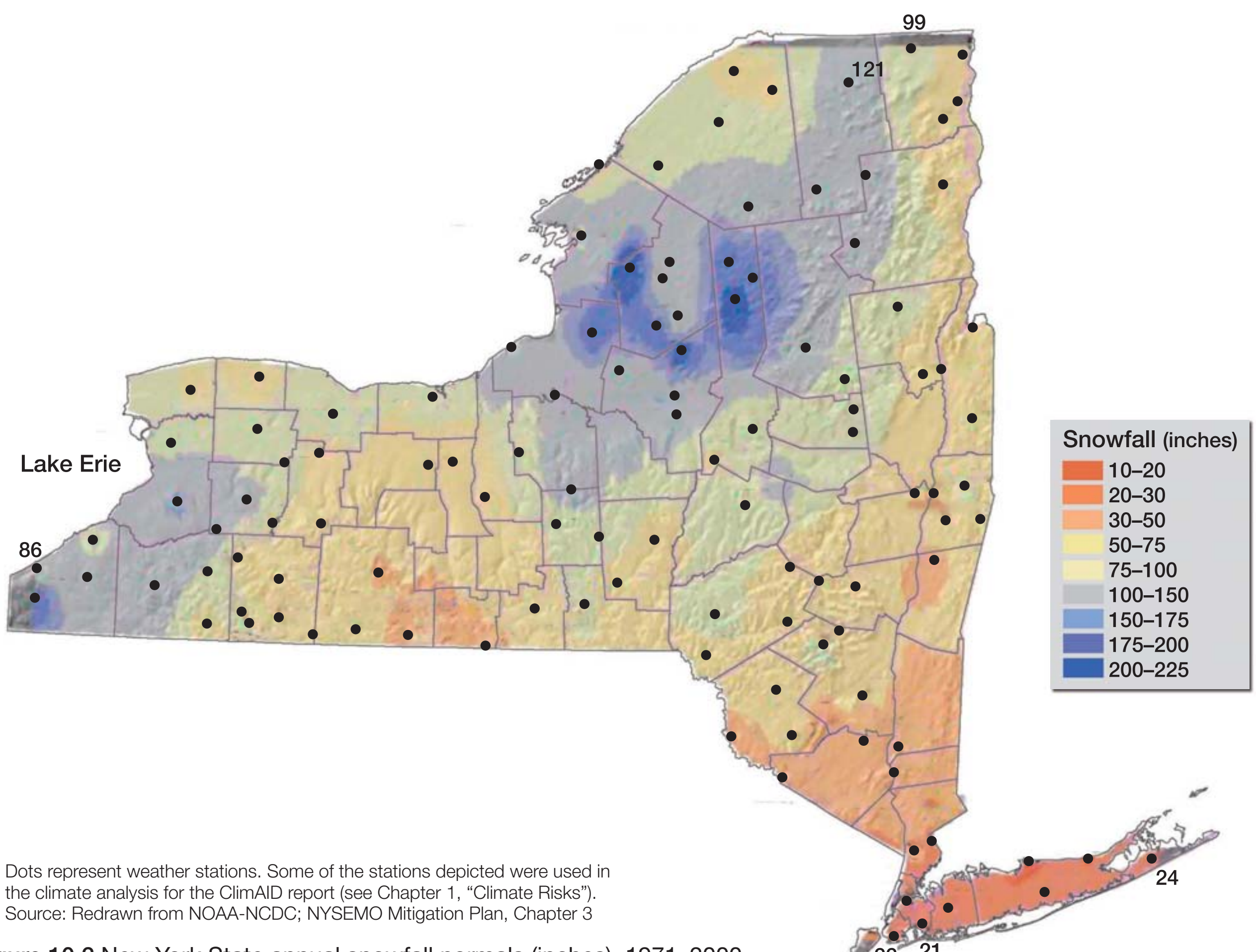
10.2.2 Precipitation

ClimAID projections for annual precipitation are for a relatively small increase through the century. However, larger percentage increases are projected in the frequency, intensity, and duration of extreme precipitation events at daily timescales. Extreme precipitation events are defined here as days with greater than 1, 2, and 4 inches of precipitation. This ClimAID projection is consistent both with theory and observed trends nationally over the last century. Intense precipitation may cause more street and river flooding and may affect low-lying infrastructure, if it is not well protected. Drought is of little consequence for telecommunications infrastructure.

10.2.3 Sea Level Rise, Coastal Floods, and Storms

Coastal flooding associated with storms is very likely to increase in intensity, frequency, and duration as sea levels rise. Changes solely in sea level rise will cause a change in coastal flood intensity, as shown in Table 5.4 (Chapter 5). More frequent future flood occurrences relative to the current 10-year and 100-year coastal flood events would occur with any increase in the frequency or intensity of the storms themselves. By the end of this century, sea level rise alone suggests that coastal flood levels, which currently occur on average once per decade, may occur once every one to three years (see Chapter 1, "Climate Risks," and Chapter 5, "Coastal Zones").

The more severe current 100-year flooding event is less well characterized than the 10-year event, because there is the possibility that the flood height may vary on century timescales. Due to sea level rise alone, the 100-year flood event may occur approximately four times as often by the end of the century. The current 500-year flood height is even less, since the historical record is shorter than 500 years. By the end of the 2100s, the 500-year flood event is projected to occur approximately once every 200 years (see Chapter 5, "Coastal Zones").



Dots represent weather stations. Some of the stations depicted were used in the climate analysis for the ClimAID report (see Chapter 1, "Climate Risks"). Source: Redrawn from NOAA-NCDC; NYSEMO Mitigation Plan, Chapter 3

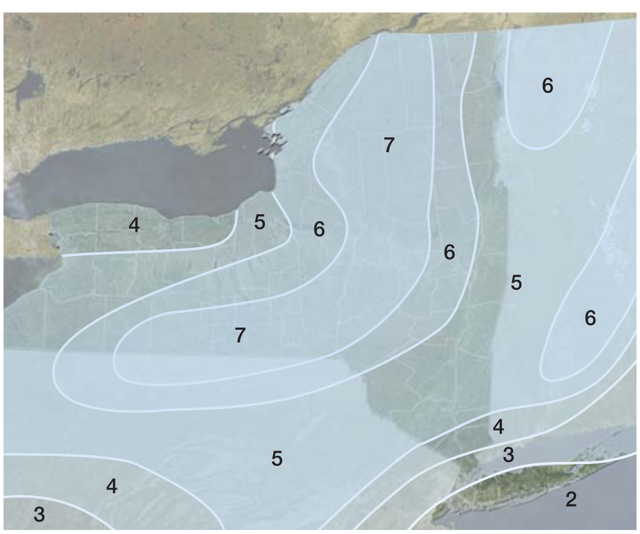
Figure 10.2 New York State annual snowfall normals (inches), 1971–2000

10.2.4 Other Extreme Events

For some types of extreme climate events that may have a large impact on telecommunications infrastructure, future climate changes are too uncertain at local scales to allow quantitative projections. In these cases, ClimAID provides qualitative information. These largely storm-related events include:

- frozen precipitation (snow, ice, and freezing rain);
- large-scale storms (tropical storms/hurricanes and nor'easters) and associated extreme winds;
- intense precipitation of short duration (downpours of less than one day); and
- lightning.

Snowfall
Snowfall is likely to become less frequent for much of the state in the coming decades, with the snow season decreasing in length. However, the coldest areas and the areas directly downwind of the Great Lakes may experience more snowfall due to greater moisture availability during the cold season when the lakes are not covered as much by ice as they once were. **Figure 10.2** shows the annual snowfall normals for New York State, with the highest accumulations in the Adirondacks (exceeding 200 inches per year), and in western New York. The lake effect on snow accumulations is clearly visible on the eastern shores of both Lake Erie and Lake Ontario.



Source: Redrawn from Changnon and Karl, 2003; basemap NASA

Figure 10.3 Contours of the average number of days per year with freezing rain for the 1948–2000 period

Ice Storms and Freezing Rain
Ice storms and freezing rain have disproportionate effects on communication infrastructure and on society at large. During the 52-year period from 1949 to 2000, freezing rain caused more than $16.3 billion in total property losses in the United States (Changnon, 2003).

New York has the highest average occurrence of ice storms of all the lower-48 U.S. states (Changnon and Karl, 2003). **Figure 10.3** shows the contours for the average number of days per year with freezing rain, based on data for the 1948–2000 period. There are, on average, seven days per year of freezing rain conditions in a curved band from western through central to northeastern New York. The number of days with freezing rain per year trails off to lower values (around five days per year of freezing rain) toward Lake Ontario. Even fewer days with freezing rain (two to three days) are observed toward New York's Atlantic coast.

Hurricanes
Hurricanes are a form of tropical cyclone. They need warm ocean surface temperatures to gain strength, and they diminish in power when they move over colder oceanwater or over land, becoming tropical storms or tropical depressions. ClimAID projects that intense hurricanes and associated extreme wind events are more likely than not to become more frequent due to expected warming of the upper ocean in the tropical cyclone genesis regions (where storms, including hurricanes, form). However, because changes in other critical factors for tropical cyclones are not well known, there is the possibility that intense hurricanes and their extreme winds will not become more frequent or intense. It is also unknown whether the most probable tracks or trajectories of hurricanes and intense hurricanes may change in the future.

Downpours and Other Events
Downpours—defined as intense precipitation at sub-daily, but often sub-hourly, timescales—are likely to increase in frequency and intensity. Changes in nor'easters and lightning storms are currently too uncertain to support even qualitative statements.

10.3 Vulnerabilities and Opportunities

The following provides examples of specific extreme weather events that have affected telecommunications, illustrating current vulnerabilities.

10.3.1 Ice Storms

One climate extreme that telecommunications is vulnerable to is ice storms. This section describes some of the major ice storms that have affected New York State and their impacts to telecommunications.

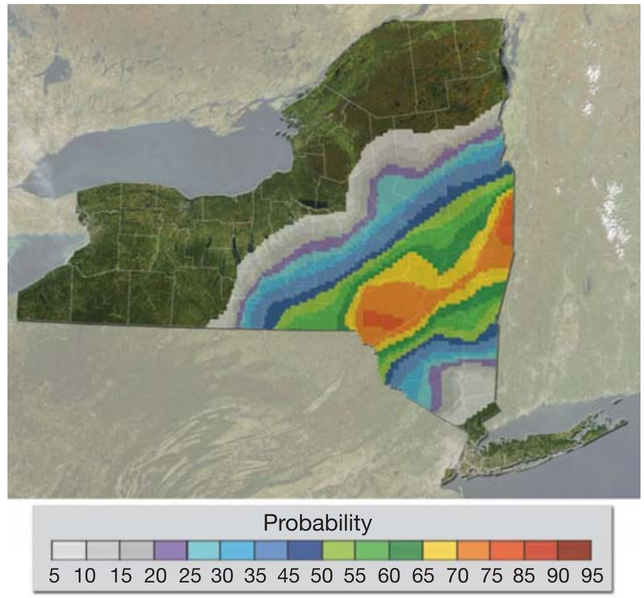
New York and New England: December 11–12, 2008

The December 2008 ice storm in New England and Central and Upstate New York formed late on December 11 and meteorologically dissipated by December 12. Its impact, however, lasted for more than a week in New York and in large portions of New England. The forecast probability for freezing rain associated with this storm is shown in **Figure 10.4.**

The band of icing from the storm traversed some populated areas and, as a result, caused a large amount of damage, even though the ice thickness generally stayed below 1 inch. More than 1.4 million customers lost power in six states. Several days after the storm, more than 800,000 customers were still without power; almost a week after the storm, more than 100,000 customers were still without power, affecting the holiday-shopping season and crippling the business and transportation sectors in many Northeast cities. Some 85 percent of customers had power restored within five days, and full restoration was accomplished within eight days for the entire affected region.

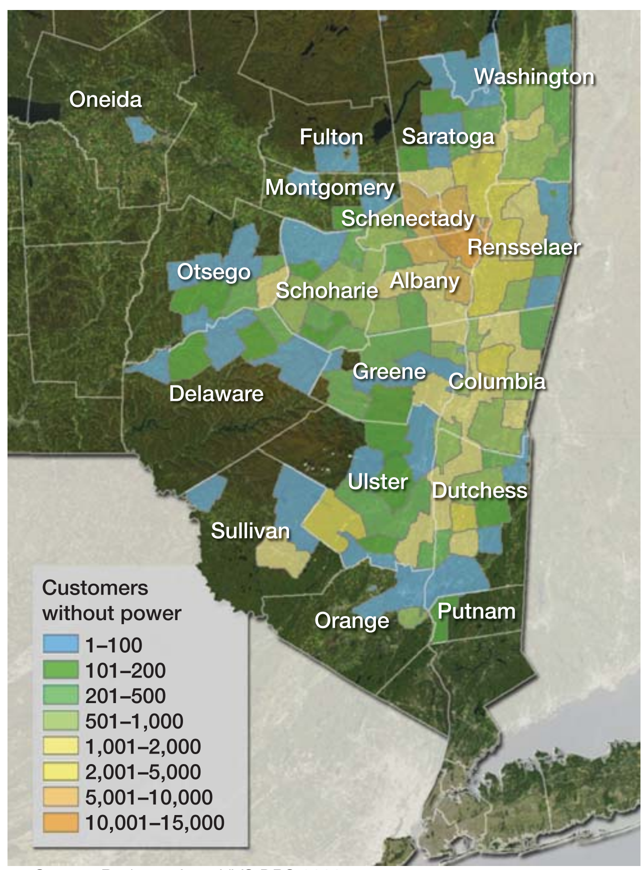
Telecommunications services were disrupted as a result of damaged lines, and electronic equipment in homes lost power. Cable-provided voice, video, and data services had problems at twice the normal levels during the week following the storm. Damage was primarily a result of fallen trees, utility wires, and poles, which were coated in a heavy layer of ice. The slow return of power in the aftermath of the storm resulted in a great deal of controversy about why the utilities could not restore services more expediently, if not avoid outages in the first place.

New York declared a state of emergency in 16 counties. Up to 300,000 utility customers lost service (**Figures 10.5** and **10.6**) in an area largely centered on Albany. By Sunday evening, December 14—three days after the beginning of the storm—an estimated 126,000 people were still without power. Power in the area was not fully



Source: Redrawn from NOAA-NWS 2008

Figure 10.4 Forecast of freezing rain probabilities for December 12, 2008



Source: Redrawn from NYS DPS 2009a

Figure 10.5 Areas with electric power outages in New York State as a result of the December 12, 2008 ice storm restored until December 19, over a week after the storm began (**Figure 10.7**).

The American Red Cross of Northeastern New York opened multiple shelters around Albany to give residents a warm place to stay and eat. At least four deaths were attributed to the storm. Three of the deaths (two in New York) were caused by carbon monoxide poisoning, the sources of which were gas-powered generators used indoors.

Hotels, hardware stores, malls, and restaurants that either had power or had a generator saw a boom in business during that weekend, as many residents finished holiday shopping, ate, and sought warmth. Most schools closed on Friday, December 12, and some colleges ended the semester early due to the severity of the storm.

Federal disaster aid topped $2 million for the nine New York counties that suffered damages from the December 2008 ice storm. Aid distributed to these counties and the State of New York is listed in **Table 10.1**.

Several weeks after the New England storm, a similar ice storm struck the midwestern United States, knocking out power to a million people and leading to at least 38 deaths.

Of note is that most outage reports cover the failure of power. Only some of these outages lead to telecommunications failures, which more commonly are experienced by consumers and less often by service providers. No consistent data for the failures of telecommunications services are in the public domain for the 2008 ice storm nor are such data available for many of the other storms described below, unless otherwise indicated.

Western New York State: April 3–4, 2003

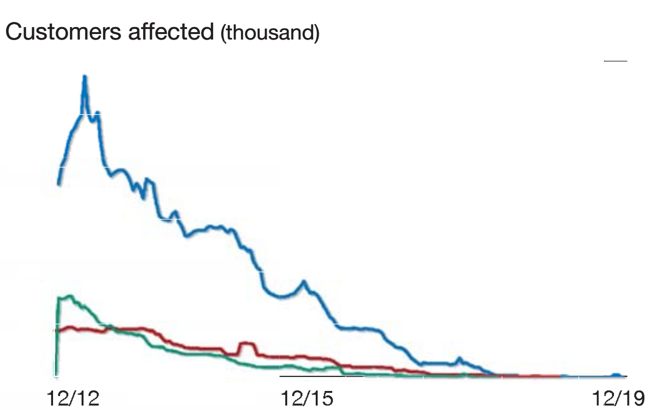
During this ice storm, 10,800 telecommunications outages were reported. It took 15 days from the beginning of the storm to return conditions to normal. More than $25 million in federal aid was provided to help in the recovery (FEMA, 2003).

Northeast United States and Canada: January 4–10, 1998

The extent, thickness of accumulated ice, duration, and overall impact of the January 4–10, 1998, ice storm are

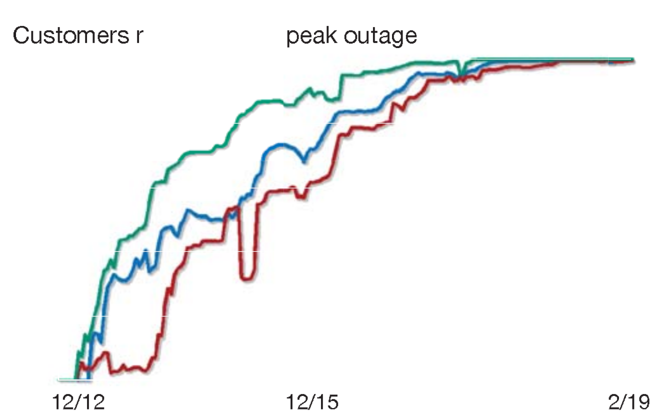
County	Federal Aid
Albany County	$295,675
Columbia County	$123,745
Delaware County	$324,199
Greene County	$203,941
Rensselaer County	$203,079
Saratoga County	$166,134
Schenectady County	$300,599
Schoharie County	$324,569
Washington County	$173,393

Table 10.1 Federal aid distributed to New York Counties as a result of the December 2008 ice storm



Source: NYS DPS 2009a

Figure 10.6 Number of reported customers with power outages versus time during the December 12–19, 2008 ice storm



Source: NYS DPS 2009a

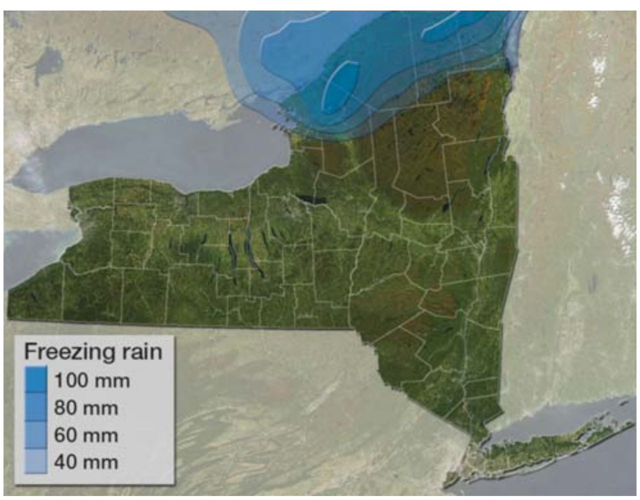
Figure 10.7 Percentage of customers with restored power versus restoration time during the December 12–19, 2008 ice storm considered the most severe of any ice storm to hit eastern North America in recent history (DeGaetano, 2000). The storm affected both Canada and the United States (**Figure 10.8**).

In northern New York, tens of thousands of people living in isolated rural areas lost power and/or telephone service. Power was not restored in all parts of Jefferson County until 25 days after the start of the storm. It took another two to three weeks for services to be fully restored. Approximately 129,000 telecommunications problems were reported to one company (Jones and Mulherin, 1998; NYS PSC, 2007).

Emergency communications systems became stretched beyond capacity as a result of the ice storm. There was a sudden increase in emergency radio communications, and a number of calls were blocked because of overload of lines (**Figure 10.9**).

Pre-1998 Ice Storms Affecting New York State

Between 1927 and 1991, at least seven severe ice storms affected New York and/or New England states. Descriptions of their effects are given in USACE (1998). **Figure 10.10** depicts one of these storms, which devastated western and northern New York, Vermont, New Hampshire, and Massachusetts in 1991.



The blue-shaded areas represent freezing rain accumulations of more than 1.5 to nearly 4 inches (40–100 millimeters; 20-millimeter gradient). Affected areas reached from Lake Ontario to Nova Scotia, including four U.S. states (New York, Vermont, New Hampshire, and Maine) and four Canadian provinces (Ontario, Quebec, New Brunswick, and Nova Scotia). Source: Redrawn from Federal Communications Commission Spectrum Policy Task Force: Report of the Spectrum Efficiency Working Group. November 15, 2002; basemap NASA, based on data from Environment Canada

Figure 10.8 Distribution of ice accumulations between January 4 and 10, 1998

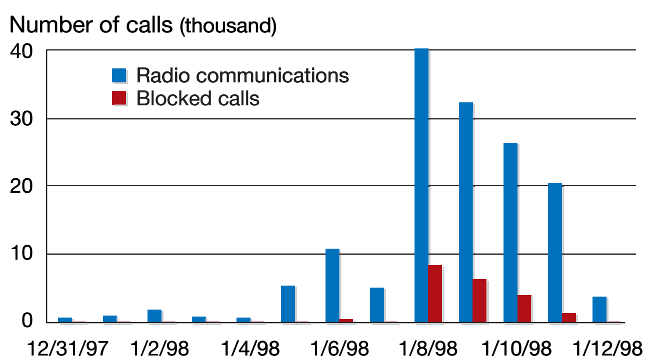
Six additional reported severe ice storms during this period occurred on the following dates:

- February 14–15, 1986
- January 8–25, 1979
- March 2–5, 1976
- December 22, 1969–January 17, 1970
- December 4–11, 1964
- December 29–30, 1942
- December 17–20, 1929

10.3.2 Hurricanes

To have maximum effect on the New York City metropolitan area, a hurricane would have to make landfall on the New Jersey coast, between Atlantic City and Sandy Hook. Since New York has not been directly impacted by a serious hurricane for the past several decades, this analysis uses hurricanes that have hit in the Gulf States as examples of the potential impact such a hurricane could have on telecommunications infrastructure in New York.

In 1938, the highest-category storm New York State has experienced made landfall in central Long Island, east of New York City (Hurricane Saffir Simpson 3). New York City was spared from the storm's worst effects, because the eastern side of the storm did not directly hit the city. (In the Northern Hemisphere, the eastern side is associated with the highest wind speeds and storm surges.)



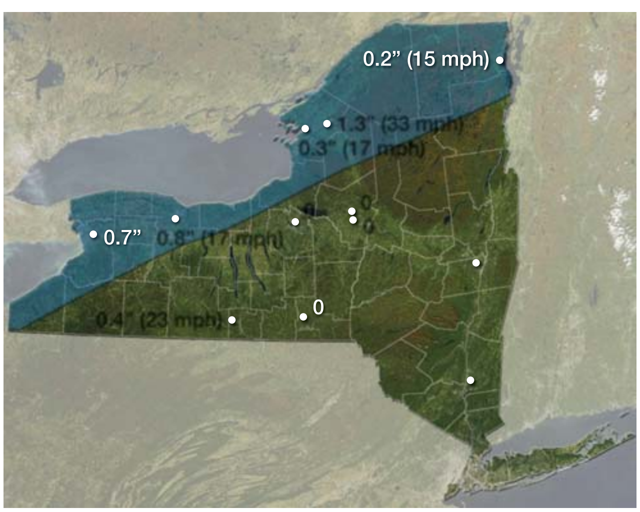
The first five days show normal background traffic, prior to when the storm hit. Source: http://www.stanford.edu/~rjohari/roundtable/sewg.pdf

Figure 10.9 Number of emergency radio communications per day and blocked calls because of overload in a single New York State county during the 1998 ice storm

Hurricane Katrina: August–September 2005

An excellent source of information on telecommunications vulnerabilities that became apparent with Hurricane Katrina, which made landfall as a category 3 storm, is FCC (2006). Hurricane Katrina struck the Gulf Coast in August 2005 and caused widespread flooding and wind damage, both of which affected telecommunications infrastructure. The duration of power outages during Hurricane Katrina exceeded the length of time that back-up batteries and fuel to power generators could supply communications. There were no means nor any plans and too many obstacles to restock fuel and batteries. Fuel to power the base stations lasted 24–48 hours, and batteries for portable radios lasted 8–10 hours. Thirty-eight 911 call centers went down and lacked an advance plan for rerouting calls. Most call centers in the low-impact areas took 10 days to restore. More than 3 million customer telephone lines lost phone service due to damage to switching centers and the fiber network and lack of sufficient diversity in the call-routing system.

Figure 10.11 shows the spatial distribution of causes of wired telephone system failure; lack of fuel supply for standby power features prominently. **Figure 10.12** indicates the failure mode for wireless services. In the area that experienced the largest service loss, diesel fuel ran out for back-up generators and supplies could not be replenished in time. It took 10 days to restore 90 percent of phone service.



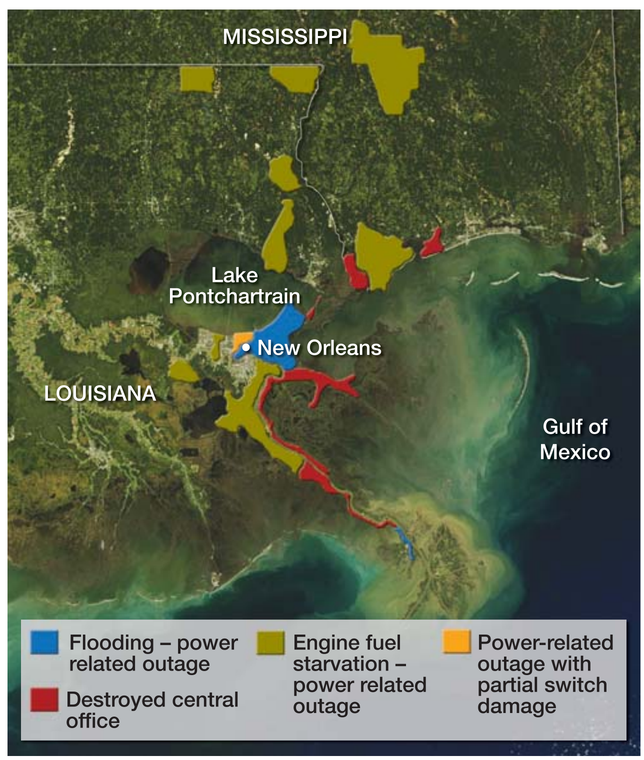
Source: Redrawn from (USACE, 1998), basemap NASA

Figure 10.10 Ice loads (inches) and wind speeds (mph) reported for the March 3-6, 1991 ice storm

In all, 35 broadcast radio stations failed, and only 4 stations worked during the storm. Also, 28 percent of television stations experienced downtime in the storm zone.

Hurricane Ike, September 2008

Hurricane Ike made landfall as a strong category 2 hurricane on September 13, 2008, near Galveston, Texas. On September 15, 2008, 75 percent of one company's customers in coastal Texas did not have service. Service was restored over the following days, with 60 percent lacking service on September 17, 48 percent on September 23, 30 percent on September 24, and 20 percent on September 26. As much as seven weeks later, some TV channels were not operative in severely hit areas. Most satellite TV customers also lost service. In the greater-Houston region, the functionality of cell phone services, on average, ranged between 60 and 85 percent in the days immediately following the storm in September 2008.



Note: Central office is where subscriber lines are connected to a local service loop. Source: Redrawn from: https://netfiles.uiuc.edu/akwasins/www/ Intelec06_Katrina.pdf; basemap: Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC

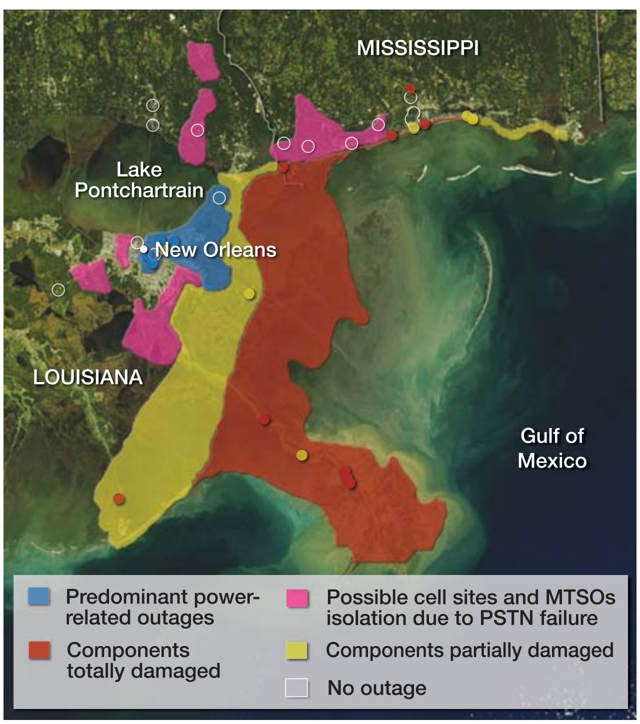
Figure 10.11 Failure modes of the wired telephone systems after Hurricane Katrina

10.3.3 Rain, Wind, and Thunderstorms

Rain is generally of little consequence for communications facilities, except when buried facilities or central offices are flooded during urban flash floods or by overflow from nearby flooding rivers. Wind and thunderstorms are more substantial hazards to above-ground communications facilities, in part from falling trees and downed wires.

Nationally, an example was a windstorm in Washington State on December 16, 2006. Approximately 15,000 customers lost high-speed Internet for up to 48 hours. Rural areas in Kitsap and east King Counties experienced service disruptions. More than 46,000 customers lost telephone service between December 16 and 22; distribution-plant and power problems interrupted service for another 100,000 telephone customers, 400,000 Internet customers, and 700,000 television customers.

Closer to home, New York State experienced, for instance, the 1998 Labor Day thunderstorm affecting the Rochester to Syracuse and Utica regions. Approximately 37,000 telecommunications trouble reports were filed. It took 16 days from the start of the storm for service to return to normal.



Circles show the locations (cell towers) included in the sample. MTSO stands for mobile-telephone switching office (which connects all individual cell towers to the central office); PSTN for public switched telephone network (which connects landline services).
Source: Redrawn from https://netfiles.uiuc.edu/akwasins/www/Intelec06_Katrina.pdf; basemap credit: Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC

Figure 10.12 Zones of predominant failure type of wireless phone services

10.3.4 Extreme Heat and Heat Waves

Most heat-wave-related outages for the telecommunications sector are related to power outages that, in turn, are related to unmet peak power demands for air conditioning. Because of these similarities, see the example discussed below in Section 10.3.6, "Electric Power Blackouts."

10.3.5 Snowstorms

Several recent noteworthy snowstorms that affected either power or telecommunications systems, or both, in New York revealed considerable vulnerabilities of the telecommunications systems, often in connection with power failures.

Western New York: October 2006

Wet snow fell on October 13, when there was still foliage on the trees and many of them snapped under the heavy load (NYSDPS, 2007). From October 13 to November 10 (29 days), there were 93,000 reported disruptions to telephone service affecting one company's customers out of the roughly 475,000 access lines (i.e., an outage rate of about 19.6 percent) in the area affected by the storm. The company replaced about 350 downed poles and about the same number of distribution and feeder cables, and it repaired about 46,000 drop wires (i.e., wires connecting poles to homes or other buildings). **Figure 10.13** shows customer-reported service disruptions and the service restorations over the 29-day period that it took to fully restore wired phone services.

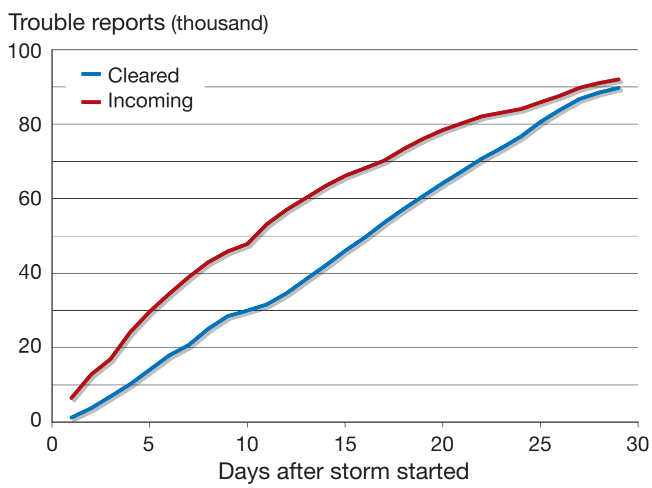
Power failures on Friday, October 13, affected approximately 400,000 customers as a result of the storm. The power companies completed restorations to full electrical service in 10 days. It took almost three times as long to complete restoration of wired telephone and cable TV services. From October 13 to November 10 (29 days), one company reported 149,000 cable television outages and repaired 46,000 lines. Most of the cellular services functioned normally during the storm, except when the back-up power was depleted and when cables that connect the cellular facility to the wired network went down. Cellular service was restored within six days after the storm, although some customers could not recharge their cell phone batteries until day 10 when power was restored fully.

New York: 1987

An early season snowstorm hit New York State in October 1987. Areas from Westchester County to Glens Falls received heavy, wet snow, with accumulations of over 20 inches observed in parts of the Catskills. This storm was the earliest measurable snowfall in Albany, which recorded 6.5 inches of snow. The heavy, wet snow fell onto leaved trees, causing numerous telecommunications outages. There were approximately 43,000 telecommunications trouble reports from this storm. The duration from the start of the event to normal conditions was 14 days.

10.3.6 Electric Power Blackouts

Although not directly linked to weather, recent electric power blackouts in the Northeast can serve as examples that show the relationship between electric grid outages and telecommunications outages.



The total number of service outages amounted to ~93,000. The difference between the two lines is the number of customers known at any given day to have no service. Note the drawn-out reporting of outages. The largest number of known, not-cleared outages (about 21,000) falls on Day 12. Restoration of wired phone services was completed on Day 29.
Source: Raw data taken from October 2006 Western New York Snowstorm Report (NYSDPS, 2007)

Figure 10.13 Total number of incoming trouble reports of customers without service (red), and number of cleared troubles (blue), versus days after start of the storm

Northeastern United States: August 14, 2003

This event had no direct weather-related cause, but demonstrates the relationship between telecommunications and electric grid outages—especially if they persist for some time. The grid power was out for 12 to 36 hours in virtually the entire northeastern United States and parts of adjacent Canada (NYSDPS, 2004).

The blackout affected an estimated 45 million grid customers in the United States and 10 million in Canada. According to the relationship between the annual frequency of outage occurrence versus number of affected customers (**Figure 10.14**), the extent of the blackout was the equivalent to a 20-year event in the United States.[6] The loss of electricity to 6.3 million customers in New York State left approximately 15.9 million people, or 83 percent, of the state's 19.2 million residents without power.

Less than 5 percent of telephone subscribers in New York State lost their "dial tone." Most losses occurred in Manhattan, where two central offices lost back-up power. During the event, approximately 19,000 lines were out of service, the duration of which lasted from 15 to 60 minutes. For competitive local exchange carriers (CLEC), switch failures caused 714 business customers in New York City to lose their service. About 14,000 CLEC customers lost their service statewide. For wireless carriers, back-up generators at cell sites initially functioned normally, but were unable to sustain operation for the long duration of the outage. Approximately 20 percent of cell sites lost service within four hours of the blackout, and about 30 percent of cell sites lost service within 12 hours. Most cable television services were out due to the lack of power.

10.3.7 Causes of Telecommunications Outages

Communication networks are complex and vulnerable to many different types of failure.

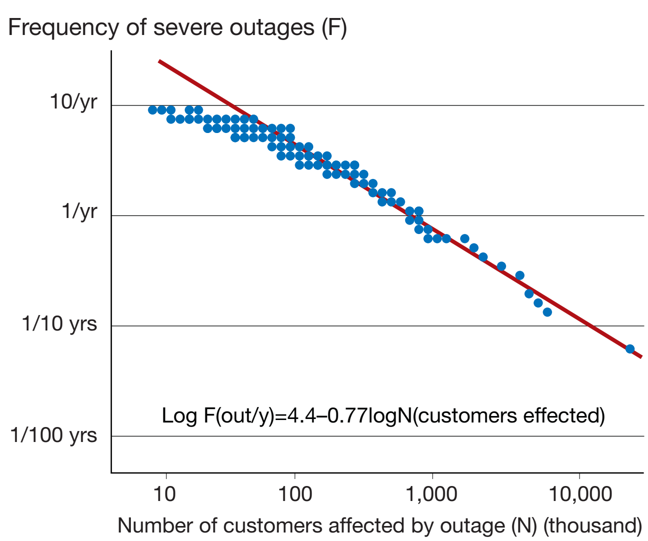
Figure 10.15 depicts the types and occurrences of failures of telecommunications networks, based on a national survey and sample period from 1993 to 2001. It indicates that power-related failures are a major cause of telecommunications outages.

Power outages, in turn, are often weather-related. **Figure 10.16** shows the rapid increase in weather-related power outages since 1992, as well as the various weather conditions that contributed to the power outages (based on a national survey). Windstorms and hurricanes dominate, followed by thunderstorms, with ice and other winter storms as the third most important contributing cause. Some of the rise in outages may be related to electricity deregulation and related dramatic decreases in tree trimming and maintenance budgets.

> The portion of all events that are caused by weather-related phenomena has tripled from about 20 percent in the early 1990s to about 65 percent in recent years. The weather-related events are more severe, with an average of about 180,000 customers affected per event compared to about 100,000 for non-weather-related events (and 50,000 excluding the massive blackout of August 2003). Data includes disturbances that occur on the bulk of electric systems in North America, including electric service interruptions, voltage reductions, acts of sabotage, unusual occurrences affecting electric systems, and fuel problems. Eighty to 90 percent of outages occur in the local distribution network and are not included in the graph. Although the figure does not demonstrate a cause-effect relationship between climate change and grid disruption, it does suggest that weather and climate extremes can have important effects on grid disruptions. We do know that more frequent weather and climate extremes are likely in the future, which poses unknown new risks for the electric grid (Karl et al., 2009).

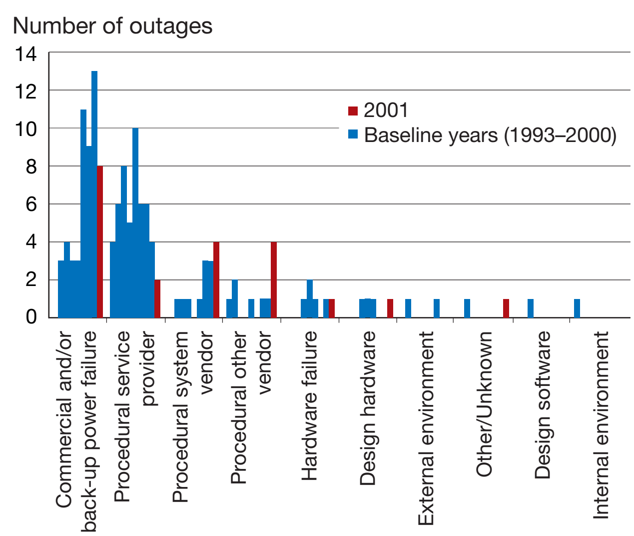
The electricity grid is vulnerable to climate change effects, ranging from temperature changes to severe weather events (see Chapter 8, "Energy"). The most familiar effects of severe weather on power lines (and telecommunications lines on the same poles) are from ice and snowstorms, thunderstorms, and hurricanes. Heat waves are associated with concurrent brown- or blackouts from overload, largely because of increased electricity demand associated with the need for air conditioning. During the summer heat wave of 2006, transformers failed in several areas of Queens, New York, due to high temperatures, causing interruptions of electric power supply.

It is not yet possible to project the effects of climate change on the power grid (or telecommunications infrastructure) at a local scale. Many of the climate effects are likely to be more localized than current climate change models can resolve. Weather-related



Based on data for the entire United States, from 1984 to 1997.
Source: Modified from https://reports.energy.gov/B-F-Web-Part3.pdf

Figure 10.14 Relationship between annual frequency of outages and customers affected in the U.S.



Note: The largest number of telecommunications outages was related to commercial grid and/or service-provider backup power failures.
Source: Bennett 2002.

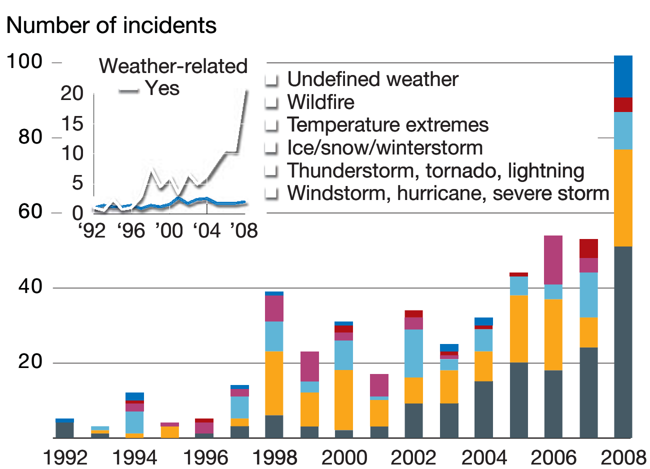
Figure 10.15 Causes of telecommunications outages from 1993 to 2001 in the U.S.

grid disturbances are recognized, however, as a challenge for strategic planning and risk management in the electric power industry primarily. Because of the interdependence between telecommunications infrastructure and power supply (**Figure 10.15**), disturbances to the power grid also affect the telecommunications infrastructure sector. This connection is expanded on in Case Study A.

Loss of communications can result in the inability to obtain assistance when needed, which can lead to the loss of life. Even brief communication outages in life-threatening situations can be devastating. During extreme weather conditions such risks are amplified. While people may not be able to communicate the need for help, the ability of responders may also be inhibited by disturbances to systems, including communication and transportation. This combination can lead to life-threatening delays.

Some of the weather-related events listed in sections above have caused telecommunication outages that have lasted two or more weeks, and in the case of Hurricane Katrina, up to several months.

The effect of the World Trade Center collapse on September 11, 2001, and the subsequent loss of communications in the Wall Street area for an extended period of time, was less costly than it might have been if recommendations to implement network relocation of facilities (by providing geographical diversity, and in some cases redundancy) had not been heeded before this catastrophic event (NYCP, 1990). An informative



Note: The number of incidents caused by extreme weather has increased tenfold since 1992. For details, see text.
Source: U.S. Global Change Research Program 2009

Figure 10.16 Significant weather-related U.S. electric grid disturbances

report was provided in the aftermath of the 2001 World Trade Center attacks. The report drew inferences about the reliability of communication systems during extreme weather conditions that can result in people being unable to obtain assistance and can lead to the loss of life (NYSDPS, 2002).[7]

10.4 Adaptation Strategies

A variety of adaptation strategies exist that can help the telecommunications sector in New York State prepare for the impacts of climate change. Described here are two types of these adaptations strategies: technical adaptations and broad-scale adaptations. Within each, specific actions that the telecommunications sector can take are discussed.

10.4.1 Key Technical Adaptation Strategies

This section explores some of the key technical adaptation strategies for the telecommunications sector. These adaptation strategies focus on changes to the physical telecommunications infrastructure and systems.

Choices: Above versus Below Ground; Wire versus Fiber Optics; Land Lines versus Wireless

Wired communication systems on utility poles are susceptible to disruption from falling trees during storms, wind and rain during hurricanes and nor'easters, and loading during ice and snowstorms. Underground communications are more susceptible to flooding. Buried and aerial fiber optics are less affected by water and water pressure than buried metallic cables, but are susceptible to freezing. Fiber optics are more dependent on power, and the regenerators need careful protection. Underground cable faults do occur less frequently, but take longer to locate and repair when they do happen.

Careful planning with due consideration of environment, climate, geography, cost, zoning laws, current plant configuration, a company's business model, etc., will determine the optimal choice for above versus below ground and wire versus fiber optics choices. Reduction of vulnerabilities can be achieved by putting the drop wires between the main wire lines and the houses of individual end-users underground. In general, the expansion of wireless services usually increases redundancy during emergencies.

Generators: Emergency Power and Strategies for Refueling

Failures of cellular systems have occurred when emergency generators are not available at cell sites and when plans are not made to store enough fuel for the generators to operate during extended climate events. The same failure mode applies to remote switching terminals or critical nodes in a wired network. In a widespread outage, companies often do not have enough generators on hand for every facility that needs one. Access to the site for refueling can be obstructed, or fuel shortages can prevent timely refueling. The same may, to a lesser extent, apply to central switching offices for wired phone services that have permanent on-site generators with contingency fuel supplies, but in extended power outages fuel may become exhausted.

Where battery banks provide the direct power equipment (48 V, DC), solar panels can extend back-up capacity. For the large power needs of urban central offices and with older switch technologies, this is not practical. But for smaller offices with the next generation of switches that promise power consumption reduction by factors of up to a thousand, this may become a practical option. The fuel supply for, and availability of, back-up power generators need to be increased at towers and at other critical locations to be able to sustain extended power outages, e.g., at wireless cell phone towers and at remote nodes in a wired network, both with potentially difficult road access.

Preventing Power Grid Failures and Loss of Central Office Functions

Strategies that can be used to adapt to power grid failures and the loss of central office include the following:

- Make a standard cell-phone-charging interface that would allow any phone to be recharged by any available charger (either powered by gasoline-fueled home generators or by cars). During extended outages, such as the recent East Coast blackouts (described in section 10.3), cell phones could not be recharged (even though commercial power or generators could be found), because the charger for one brand or model of phone was incompatible with others. A federal standard requiring all cell phones to have a standard charging interface would allow any phone to be recharged by any available charger. Since most cell phones are changed every two to three years, nearly all phones would be compatible with any charger within three years. The new generation of smart phones with charging via USB connectors promises to improve this situation. This is an action for the telecommunications industry to undertake, but state and federal agencies can help to encourage its adoption.
- Intensify the use of strategically stored mobile cells in areas where they can be quickly moved to locations where cellular towers are disabled. This solution would likely only be used when it is clear that restoration of power or telecommunications, for example to a cell site, is not faster than the deployment of mobile cells.
- Use the network to relocate communications centers or distribute the normal operation of the centers among different centers. This is an option to reduce disruptions to the economy when communication services are lost in an area. Network capacity is routinely redeployed or augmented to adapt to changes in traffic patterns, both in business-as-usual situations and following disasters. For instance, following the World Trade Center collapse, the communications destined for Wall Street were re-routed to New Jersey. This reduced the economic effects that would have resulted from an extended suspension of trading for several weeks.
- Encourage the deployment of passive optical networks that are less reliant on commercial and back-up powering in the field. A passive optical network (PON) is a point-to-multipoint fiber to the network architecture of a quality in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises.

Developing and Expanding Alternative Technologies

It is quite likely that alternative networking technologies will be developed to provide diversification across another dimension. Some networking technologies that may or may not add diversity or robustness include:

- **Free-space optics** (FSO), an optical communication technology that uses light propagating in free space to transmit data between two points. The technology is useful where the physical connections by means of fiber optic cables are impractical due to high costs or other considerations. Free-space optics is only good for a few hundred yards to maintain high reliability (i.e., better than 0.999 or 0.9999). Any longer distances will produce circuit errors in heavy rain or fog.
- Commercial versions of ***ad hoc* networking** techniques typically relying on wireless communication. *Ad hoc* networks lack a designed infrastructure and form cooperative links between users to forward data. The structure of the network reflects the bandwidth requirements of the users in an area and the availability of access to the network infrastructure. However, ultimately they depend on the connection to the backbone wired network infrastructure, except in some relatively localized settings, which may be limited to urban environments.
- **Transmission via power lines**, which would reduce redundancy and couple power and communication failures more than they are currently.
- **Delay-tolerant networking techniques**. These networks can provide emergency communications during weather-related disasters, but are limited in data rate and quality. They include, for instance, those being proposed to provide communications to nomadic reindeer herders in Arctic latitudes. They are typically applicable to e-mails and text messages that are delay-tolerant.
- **Satellite phones and ham radio operators**, which have played important roles in emergency situations. The United Nations regularly distributes satellite phones in disaster regions internationally. These phones were in high demand during Hurricane Katrina. Satellite phones continued to operate following Hurricane Katrina and more than 20,000 satellite phones were used in the Gulf Coast region in the days following Katrina. Amateur ham operators have been the lifeline in many disasters and, perhaps, should be better organized. Not only should first responders be tied to them (some local emergency offices have such arrangements), but utilities should be organized to link with them as well.

10.4.2 Larger-Scale Adaptations

This section focuses on broader adaptation strategies for the telecommunications sector.

Diversification of Communications Media

Cable television and telephone distribution networks were originally different. Telephone systems used twisted wire pairs to connect to a central office, while cable television used coaxial-cable-based tree topology. A major difference between the cable company hybrid fiber-coax networks and the traditional telephone networks is that the former are more reliant on commercial power in the field and on electronic relays and amplifiers that have no back-up capability. They are not designed to operate in a power loss or blackout. Traditional telephone networks are designed to work even after a loss of commercial power. This critical reliability difference still exists today.

To some degree, the technologies in both networks have become more similar. They both use a fiber-optic network from a central location that connects to a customer's neighborhood with a short coax (cable television), twisted pair of wires, or a fiber connection (telephone systems) from the neighborhood node to a customer's premises. Both systems provide the same services to the end users (voice communications, high-speed data, and video distribution). The more recent technologies are more power-dependent, which affects reliability, resiliency, and recovery, although some use passive optical fiber technology requiring no power for "the last mile" (i.e., the last segment of telecommunications delivery from provider to customer).

It is possible that separate cable and telephone networks may evolve into a single monopoly distribution network that may be provided by a separate private or public utility company. Companies similar to the current cable and telephone companies may compete as service providers. If this occurs, a redundancy that currently exists in the multiple distribution networks may disappear, and the network may become more susceptible to failures caused by weather-related events. However, telephone and cable lines, while separate, are not really redundant in the sense that they are located on the same poles; if the poles are damaged in a storm, both cable and telephone lines may fail.

The Hurricane Katrina communications panel recommended more diversity of call routing in wireline networks to avoid reliance on a single route. The Public Service Commission instituted such diversity requirements following the September 11, 2001, outages that largely affected New York City (discussed further below) (NYSDPS, 2002; Case 03-C-0922). This approach is useful for routing traffic between switches, but does not help when the problem is in "the last mile," near the end customer. Also, the increasing use of Internet protocol for telephone services will provide routing diversity, because the information processing system will automatically search for any surviving physical routes. On the other hand, Internet-based networks often experience more widespread outages than a traditional network does when a major node or other centralized critical function location or equipment fails. This is common because these providers must leverage economies of scale to compete with bigger traditional companies and have fewer distributed facilities and less redundancy.

Natural Competition: Wired versus Wireless Networks

Wired networks provide point-to-point links that are more secure and private and can currently support much higher total data rates in a given geographic area. Improving antenna technologies, such as multiple-input and multiple-output (MIMO),[8] will continue to change this imbalance, but it is unlikely that the data rates provided by wireless technologies will exceed the rates provided by wired networks.

While wireless networks are in general dependent on wireline networks in order to backhaul data from cell sites to the backbone network, they do provide seamless communications to mobile, untethered users. They transfer information that is broadcast to a large set of receivers more naturally than wireline systems.

The current federal and state broadband initiatives could potentially encourage competition between wired and wireless media by developing both. However, major wireline companies own large portions of the wireless companies with major market shares in New York State. The development of either technology is likely to occur naturally by consumer choice, desired data rates, and considerations of quality versus price. Whether wired communications are more likely to prevail in densely populated, disadvantaged areas, while wireless communications prevail in sparsely populated rural areas, is questionable. In either case—wireline or wireless networks— in a competitive free-market telecommunications environment, commercial operators need a customer base to support the cost of infrastructure. Rural areas will continue to have more difficulty in obtaining access to high-speed broadband than urban areas, unless it is publicly supported, or prices may tend to be higher in the rural areas that often are least able to afford them.

Prior Adaptation Policy Recommendations

It is instructive to revisit what kind of measures and actions New York State agencies have already recommended vis-à-vis experiences from past extreme events, whether of natural or manmade origins. A review of these assessments reveals that nearly all proposed policy options and recommendations for reducing communications vulnerability to extreme events, made without particular reference to climate change, are directly relevant to the kind of extreme weather events discussed in the ClimAID report.

In the context of telecommunications, there is a comprehensive document that combines many of the findings, options, and conclusions for this important infrastructure sector: *Network Reliability After 9/11*, a white paper issued by the New York State Department of Public Service (NYSDPS, 2002). While it was originally inspired by the lessons learned from the September 11 events in 2001, it looked far beyond this single event and addressed fundamental systemic telecommunications vulnerability and reliability issues.

10.5 Equity and Environmental Justice Considerations

The rapid rate of innovation in telecommunications technology and the relative impermanence of the infrastructure mean the sector is potentially in a relatively good position to respond to climate change, signaled either by perceived physical risk or price changes. Yet flexibility and mobility present some challenges to enhancing social equity and ensuring that these technologies facilitate wide-ranging social resilience rather than exacerbate isolation and lack of access to information among more vulnerable people.

Because of the rapid changes taking place in the sector, monitoring equity involves examining the distribution of and access to old technology as well as rates of adoption and use of new technology. As climate risks affect decisions about types of infrastructure to deploy and where it can be built, a number of questions stand out: Are there specific regions, communities, or demographic groups that are likely to lose out? Which types of telecommunications technology and infrastructure are inherently more resilient? Will some adaptation decisions create new vulnerabilities for those using less resilient and obsolete infrastructure?

10.5.1 Landline Dependency and Adaptation Decisions

Because of enormous growth in new technologies, telecommunication companies are increasingly losing landline subscriptions. As of mid-2008, landline subscribers in the state had declined 55 percent since 2000. This is, in part, due to competition from increasing mobile phone penetration (which, in the context of storm vulnerability, may provide higher reliability where mobile services are available). The New York landline loss rate is comparable to that of the decline in landlines in New Jersey (50 percent), but surpasses the lowest rates in Connecticut (10 percent), Texas (20 percent), and California (21 percent) (Cauley, 2008). In the last year alone, one company lost 12 percent of its landlines. At the same time, the cost of maintaining the lines is increasing, and there are reports that some companies are pulling back on the upkeep of lines (Hansell, 2009; NYS DPS, 2009b).

Amid these changes, 14 percent of Americans are neither cell phone nor Internet users (Horrigan, 2009). Some of these customers are simply late adopters, but many others are households in isolated rural areas where new technologies have simply not yet penetrated. This leaves them dependent on landlines for lifeline services in emergency situations.[9] Adaptation strategies that focus disproportionately on the use of newer technologies and on implementation in areas with opportunities for greatest cost recovery may exacerbate the relative vulnerability of those reliant on landlines in more remote locations. Natural progression of technology can have a profound and beneficial impact on the reliability of networks if combined with responsible and realistic policies to address these concerns.

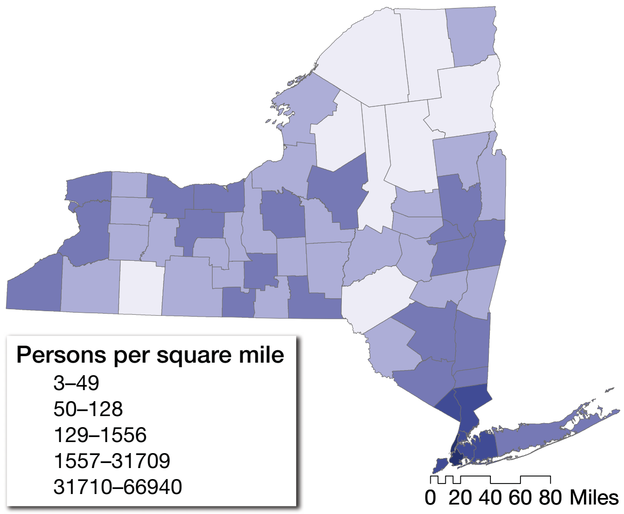
10.5.2 Cascading Inequities and Challenges

Similar to the way localized energy problems can ripple through the grid, a relatively localized disturbance to telecommunications infrastructure can create cascading impacts across regions and cripple widespread economic operations. For example, commercial transactions are increasingly reliant on credit card authorization, ATM withdrawals, and computer networks, services that are incapacitated with power and telecommunications outages (Quarantelli, 2007). Coping capacity reflects the underlying social and financial capital as well as the degree of isolation and service repair capacity. Rural and low-income communities are likely to be at a disadvantage.

On the other hand, it is possible that a progressive policy of universal service offers an opportunity to expand newer (wireless) technologies to the outer reaches of the network. This is comparable to developing nations "skipping" legacy telecommunication technologies. Cellular expansion in rural areas could make disaster recovery less burdensome (e.g., fewer drops to fix); allow utilities to pursue more efficient, centralized recovery strategies; and allow the severity of long-term power outages to be mitigated more easily. For example, rural customers are more likely to be able to use and recharge cell phones using car batteries, because vehicle ownership is more prevalent in rural areas. In contrast, modern fiber and cable networks are heavily dependent on the availability of commercial power.

10.5.3 Digital Divide

According to the 2008 State New Economy Index, New York ranks within the third quartile in terms of digital economy competitiveness (NYS Council for Universal Broadband, 2009), i.e., use of digital communication is widespread. At the same time, disparities in access to technologies and different rates of adopting them ensure that some areas and groups within New York State will benefit more than others from the potential of new information and communications technology to drive social and economic development and wellbeing. Sustainable development is an important tool for building local and regional resilience to climate stresses and shocks. Technology disparities are discussed in the next section as well as how infrastructure deployment aimed at



Source: U.S. Census 2000

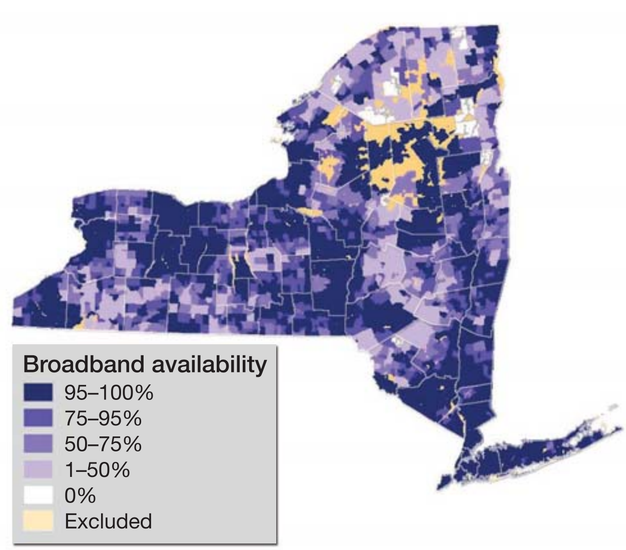
Figure 10.17 Variation in population density in New York counties

minimizing these disparities could be part of a broad adaptation strategy.

Since the 1990s, the term "digital divide" has been employed to describe persistent differences in access to digital technology based on race, gender, age, geography, and socioeconomic condition (Light, 2001). For example, in a recent survey, low-income households adopted broadband at less than half the rate of higher-income households, and a wide gap was noted between white adults and African American adults (Horrigan, 2007 and 2008).

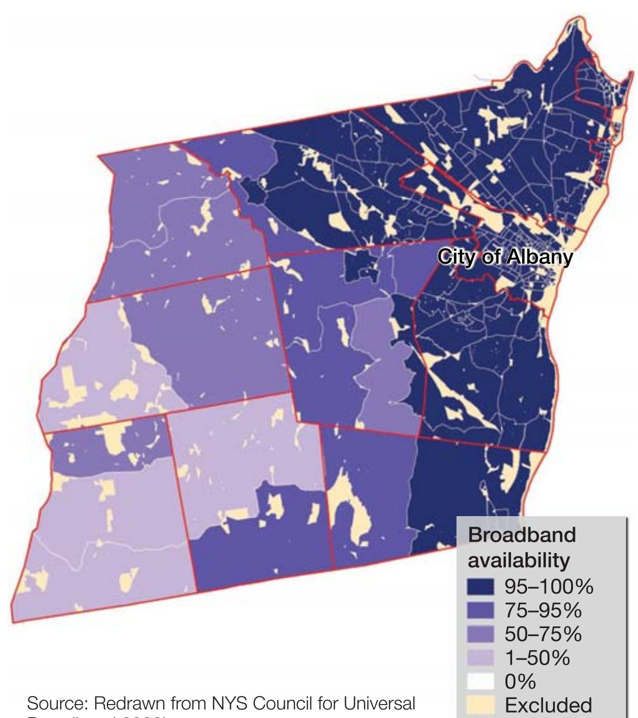
Demographic differences in rates of adopting technologies are compounded by regional differences in access to technologies. A national survey found that 24 percent of Internet users did not have broadband access because it was unavailable in their area (NYS Council for Universal Broadband, 2009a). Similarly, throughout New York State, there are communities where broadband is neither available nor affordable. The most sparsely populated counties are clustered in the Adirondack region and in Delaware and Allegany Counties (**Figure 10.17**). These areas also tend to have limited access to broadband. Notably, large parts of Franklin, Essex, and St. Lawrence have no availability at all. Compare this to the near-universal access in and around most of the state's urban centers (**Figure 10.18**). Perhaps most striking is the variation within counties. In Albany County, a noticeable division exists between urban centers such as the city of Albany, with coverage rates of 95 to 100 percent, and surrounding towns with less than 50 percent availability (**Figure 10.19**).

Access to wireless services (cell phones) is also limited in rural areas with low population densities. The same applies to the expansion of competitive wired networks, such as digital cable. Unfortunately, this is the reality of a non-regulated competitive industry. If there are not enough people to break even (much less turn a profit) on



Source: Redrawn from NYS Council for Universal Broadband 2009a

Figure 10.18 Variations in wired broadband availability (cable-modem and DSL) in New York State, February 2009



Source: Redrawn from NYS Council for Universal Broadband 2009b

Figure 10.19 Wired broadband availability (cable-modem and DSL) within Albany County, February 2009 the infrastructure required to deliver the service, it is very difficult for service providers to make that investment when other areas with higher population densities are in a similar need for additional capacity and speed. Some rural cell towers, unless they are on a highway corridor, operate at a loss. With continued downward pressure on wireless service prices, equitable distribution will continue to be a difficult problem to solve.

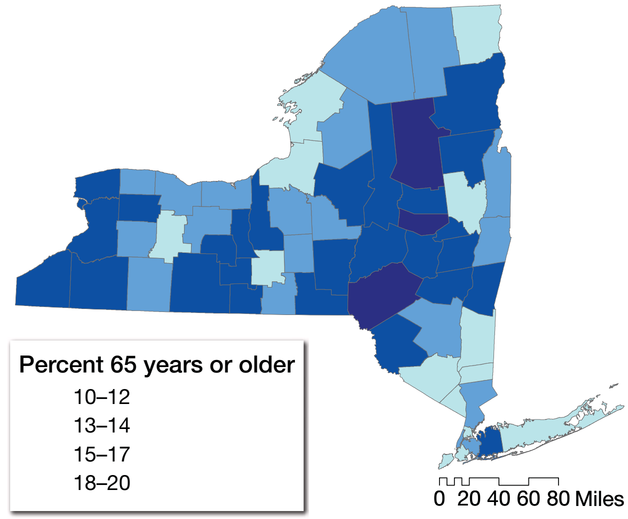
Introducing new technologies and maintaining equitable and reliable access are often conflicting. New technologies are introduced where they are most profitable, i.e., in high-density population areas. Noting this reality, short-term goals then could be to preserve service and access so that customers and critical services are not abandoned. The long-term solution should be to deploy a more reliable and equitable technology network that can be sustained by viable operators.

Another demographic trend is that lower-income groups drop landlines faster than higher-income groups and use wireless as their sole means of communication.[10] On the one hand, this reduces redundancy in emergency situations, but on the other, because wireless is less vulnerable to extreme weather events, it implies more continuity of services during extreme events as long as customers find a way to recharge their mobile batteries (e.g., via charges from cars).

10.5.4 Deploying Rural Broadband as an Adaptation Strategy

Broadening the penetration and use of affordable and fast information and telecommunications technology can help strengthen the types and degree of connectivity between lower-income rural communities and economic centers, educational options, business services, and health infrastructure.

As part of a comprehensive development strategy aimed at employment and business diversity, for example, deploying broadband could help build social and economic resilience in regions dependent on climate-sensitive industries such as agriculture and natural resources (see Figure 3.4 of Chapter 3, "Equity and Economics"). It also could help increase citizen capacity to respond to climate-related disasters via better communication of risks and preparedness strategies. 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 northern New York State as part of the federal government's broadband stimulus program.



Source: U.S. Census 2000

Figure 10.20 Regional variations in concentrations of population 65 years and older

Rural deployment of broadband would tend to target regions with higher-than-average rates of aggregate population vulnerabilities. For example, Delaware County, one of the state's most sparsely populated counties, is located within the high-risk zone for ice storms and was hard hit by flooding in 2006. On top of this, it is also among those counties with the highest rates of poverty outside of New York City (see Figure 3.2 of Chapter 3, "Equity and Economics") and the highest proportion of elderly people (**Figure 10.20**). In the current recession, lower-income rural, elderly populations are especially vulnerable to additional climate extremes. These extremes could multiply the burden of regional economic decline on the elderly and also could cause the state to roll back the social supports that serve them (see e.g., *New York Times*, 2009).

10.5.5 Equity and Equity-Governance

Focusing on the use of information and telecommunications technologies as part of a broader strategy of inclusive community participation and sustainable development opens a range of possible strategies for equitable social, economic, and environmental gains in communities that might otherwise be exposed and sensitive to a variety of climate stressors.

Following the framework identified by a 2008 report (MacLean, 2008), information and telecommunications technologies can be coordinated for first-, second-, and third-order effects. Applied to adaptation, first-order effects include using innovative forms of technology to monitor and research climate change and adaptation, as well as to disseminate information on best practices and critical vulnerabilities. Second-order effects include using social networking and emergent forms of cooperative dialogue that build adaptive capacity and enable modes of debating and evaluating potential adaptations and risks. Finally, third-order effects encompass a whole suite of networked government measures related to equity, ranging from those that facilitate access to and coordination across branches of government to those that increase procedural justice by encouraging active executive participation among isolated or disengaged stakeholders.

To adopt these strategies, citizens must have equitable access to affordable information and telecommunications technology networks and knowledge of how to use these resources. Equally important is equitable access for local governments, where wide disparities in technological infrastructure exist across local planning departments in New York State (for an example, see Gross, 2003).

On a more sophisticated level, governance strategy to enhance equity requires building local capacity (e.g., through education, new management practices, behavioral changes) so that communities and governments have the means to creatively use technology for information gathering, dialogue, or participation. However, no amount of access can overcome persistent ignorance about how and when to use technology. Situations in which people do not know how to use technology may generate a false sense of security or control. In some cases, this can even increase vulnerability when the equipment malfunctions at a critical stage.

Telecommunication systems are designed so that the installed capacity can handle the typical daily peak traffic load. Add in a disaster, and the system will likely be overwhelmed. As long as telecommunications companies running the networks have to pay to operate and maintain the infrastructure on a competitive basis, change is unlikely. Wireless phone technology (and, to some extent, landlines) can augment capacity fairly quickly when needed in emergency situations. Some capacity-enhancing measures can be implemented immediately, trading off voice quality for additional traffic. Adding radios and backhaul capacity can take a few days, depending on the situation.

A useful adaptation strategy is to educate people about the impacts their behavior will have on a network during a disaster. To educate customers to send a text message about the tornado, as opposed to taking a picture and sending it from their cell phone (which uses more network capacity), is one example.

10.5.6 Information and Telecommunication Technology Adaptation Strategies and Climate Change Mitigation

Any significant expansion of information and telecommunications technology services needs to be evaluated with respect to the impact of increased energy use on household budgets. The expansion also needs to be evaluated with regard to its wider impact on greenhouse gas emissions. Cooling and operating more information and telecommunications technology servers and applications will result in increased energy demands. These processes already account for 1.5 percent of the energy consumption in the United States, and it is a percentage that is growing quickly (*The Economist*, 2008). Evaluating the efficiency gains of new technologies relative to this increased energy usage is a critical area for further research.

10.6 Conclusions

As discussed in this ClimAID chapter, telecommunications is an essential sector that is vital to New York State's economy and welfare. It is largely privately operated but has important public functions. Because of rapidly changing telecommunications technology and deregulated, fiercely competitive markets, some service providers tend to focus on short-term market share and profitability rather than pursuing long-term strategies to achieve reliability and redundancy. Business planning horizons are at most five to ten years, which is short compared to projected climate change trends over many decades. Even under current climate conditions, there are serious vulnerabilities that prevent the telecommunications sector from uniformly delivering reliable services to the public during extreme events. New York State can proactively engage industry to help prepare for more severe and more frequent extreme climate events in the future.

10.6.1 Key Vulnerabilities

The telecommunications sector is vulnerable to several climate hazards, many of which are projected to change in the future with climate change. The sector's key vulnerabilities include the following:

- Telecommunication service delivery is vulnerable to severe wind, icing, snow, hurricanes, lightning, floods, and other extreme weather events, some of which are projected to increase in frequency and intensity.
- In coastal and near-coastal areas, sea level rise in combination with coastal storm-surge flooding will be a considerable threat during this century to some central offices and underground installations. This risk extends up the tide-controlled Hudson River to Albany and Troy.
- The delivery of telecommunications services is sensitive to power outages, some of which result from increased energy demands during heat waves. Heat waves are expected to increase in frequency and duration.
- Telecommunication lines and other infrastructure are vulnerable to the observed and projected increase in heavy precipitation events resulting in floods or icing during freezing rain.
- Populations in underserved areas, especially in remote rural areas, often have only one type of service and hence lack redundancy. They may have difficulty reporting outages during extreme events and potentially life-threatening emergencies. For instance, during ice or snow storms, mobility can be severely hindered.

10.6.2 Adaptation Options

There are adaptation options and opportunities that can help the telecommunications sector prepare for the impacts of climate change. Key adaptation options and strategies include the following:

- Make the backbone network redundant for most if not all service areas, and resilient to all types of extreme weather events; provide reliable backup power with sufficient fuel supply for extended grid power outages.
- Decouple communication infrastructure from electric grid infrastructure to the extent possible, and make both more robust, resilient, and redundant.
- Minimize the effects of power outages on telecommunications services by providing backup power at cell towers, such as generators, solar-powered battery banks, and “cells on wheels” that can replace disabled towers. Extend the fuel storage capacity needed to run backup generators for longer times.
- Protect against outages by trimming trees near power and communication lines, maintaining backup supplies of poles and wires to be able to replace expediently those that are damaged, and having emergency restoration crews at the ready ahead of the storm’s arrival.
- Place telecommunication cables underground where technically and economically feasible.
- Replace segments of the wired network most susceptible to weather (e.g., customer drop wires) with low-power wireless solutions.
- Relocate central offices that house telecommunication infrastructure, critical infrastructure in remote terminals, cell towers, etc., and power facilities out of future floodplains, including in coastal areas increasingly threatened by sea level rise combined with coastal storm surges.
- Further develop backup cell phone charging options at the customer’s end, such as car chargers, and create a standardized charging interface that allows any phone to be recharged by any charger.
- Assess, develop, and expand alternative telecommunication technologies if they promise to increase redundancy and/or reliability, including free-space optics (which transmits data with light rather than physical connections), power line communications (which transmits data over electric power lines), satellite phones, and ham radio.
- Reassess industry performance standards combined with appropriate, more uniform regulation across all types of telecommunication services, and uniformly enforce regulations, including mandatory instead of partially voluntary outage reporting to the regulatory agencies.

- Develop high-speed broadband and wireless services in low-density rural areas to increase redundancy and diversity in vulnerable remote regions.

10.6.3 Knowledge Gaps

The industry generally lacks computerized databases that readily show the location and elevations of installed telecommunication facilities and lifelines and their operational capacity. Such data can be crucial in extreme weather events to make rapid damage, loss, and consequence assessments in potential hazard and damage zones. For security reasons, such databases need to be fully protected to allow only restricted, authorized accessibility.

The public lacks standardized easy access to information on service outages and expected restoration times. This information can be crucial in response actions taken during emergencies, by public first responders, businesses, and private households. Some consideration must be given to what kind of information is publicly accessible and what additional information is only accessible to authorized parties (government, first responders, etc.), because of security reasons. But these concerns must not prevent the public from having ready access to information in order to minimize the potential impact of emergencies.

A sound financial model is needed for telecommunications companies to implement costly reliability and resiliency measures and to remain competitively viable, since these companies 1) have obligations to serve high-cost rural customers, and 2) provide backbone services for all other communication modes described in this report.

The ClimAID assessment suggests both technical and policy options for effective adaptation strategies and reducing vulnerability/improving resilience. The following potential responses emerge from this assessment:

- Overcome the lack of and unevenness in transparency with respect to reporting and assessing vulnerabilities to climate-related hazards for both the current and future communication infrastructure systems and operations. Attune state actions to balancing the competing needs for public safety versus concerns for free-market competition and cyber security.
- Perform a comprehensive assessment of the entire telecommunications sector's current resiliency to existing climate perils, in all of their complexities. Extend this assessment to future climate projections and likely technology advances in the telecommunications sector. This includes the assessment of co-dependency between the telecommunications and power sectors' relative vulnerabilities. Provide options and incentives to decouple one from the other while improving resiliency of each.
- Implement measures to improve public safety and continuity of communications services during extreme events. Any such actions need to be risk-informed and need to consider the benefits versus costs to both the public and the industry for increased resilience to extreme events. They need to foster security for both the public and the industry and simultaneously advance competition, technological innovation, and equitable and affordable customer access across the state.

Case Study A. Winter Storm in Central, Western, and Northern New York

This ClimAID case study analyzes the impacts of a severe winter storm in central, western, and northern New York State, concentrating on two specific climate hazards based on geographic location in the state. For central New York, the focus is on an ice storm that produces freezing rain and ice accumulation. Snow accumulation is the focus for western and northern New York.

The case study's primary focus for the societal impacts of the winter storm is on the telecommunications infrastructure. However, a secondary area of examination is the effects of the winter storm on the electric power grid.

Ice Storm Scenario

Severe winter storms in New York generally follow a certain pattern, as described in section 10.2. A low-pressure system moves up the Atlantic Coast bringing warm moist air that encounters cold dry air in a high-pressure system over Canada and extends into the northern parts of New York. The northward movement of the counterclockwise-rotating storm system causes warm air to overrun the cold air mass. This typically forms three moving bands of precipitation (**Figure 10.21**):

- a southwest-northeast band of heavy rain closest to the coast
- parallel to it but farther inland, a band of freezing rain (ice)
- farther toward the northwest, another parallel band of precipitation that gradually grades from snow pellets into snow

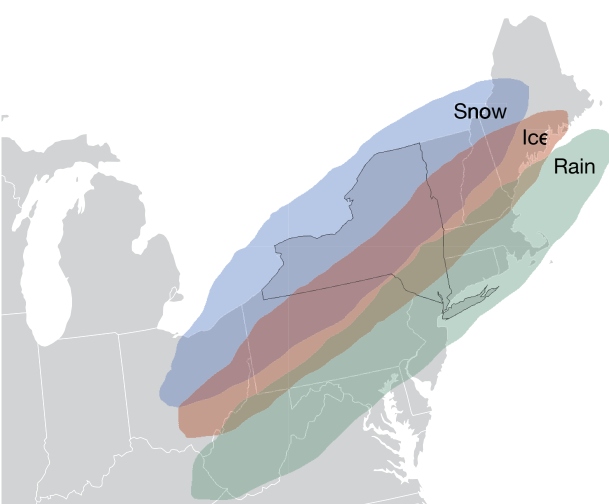
The jet stream's position, strength, and persistence, as well as other meteorological factors, determine how large the storm system is; where and how fast or slowly it moves; how much total precipitation it will produce as rain, freezing rain/ice, and snow; how wide and long the three bands of precipitation stretch; and how the bands move in time and, hence, how long each phase of precipitation lasts at any location. Any given location may go through more than one precipitation phase (from rain to freezing rain to snow pellets to snow), while other locations may be affected only by a single precipitation band.

In this case study, a hypothetical composite of historical extreme winter storms is assumed. While the three precipitation categories (rain, freezing rain, and snow) would not necessarily be expected to occur concurrently in these proportions, each of these types of extreme winter precipitation is currently expected to occur on average at least once per century:

- up to 8 inches of rain falling in the rain band in near-coastal New York over a period of 36 hours
- up to 4 inches of freezing rain precipitating in the ice band in central New York, of which between 1 and 2 inches (radial, i.e., the thickness of accumulated ice as measured outward from the collection surface, such as a twig) accumulates as ice, over a period of 24 hours
- up to 2 feet of snow accumulating in the snow band in northern and western New York over a period of 48 hours

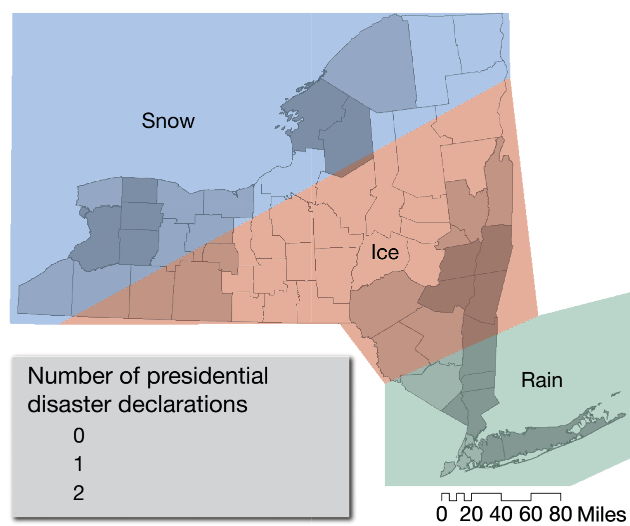
Figure 10.22 shows the three precipitation bands of the scenario storm system in relation to county boundaries within the state. The center of the ice band covers the cities of Binghamton, Albany/Troy, and Schenectady, and several rural areas in between and in their vicinity. The snow band covers Buffalo, Rochester, Syracuse, Utica, Plattsburg, and the Adirondacks. The rain precipitates over Long Island, New York City, and the mid-Hudson Valley counties to halfway between New York City and Albany.

Of New York State's 62 counties, 12 are assumed to be dominated by rain and about 20 by snow; about 30 are subjected to freezing rain. The county population density varies significantly from extreme urban (65,000



Note: The ice band includes a zone in New York State stretching from Binghamton through Albany into the Berkshires.

Figure 10.21 Typical pattern of severe winter storms in New York State



Source: Redrawn from NYSEMO historic map of presidential disaster declarations of winter storms in New York State for 1953 to 2007

Figure 10.22 Approximate overlay of the precipitation bands for the winter storm analyzed in the case study people per square mile in Manhattan) to very rural (three people per square mile in Hamilton). Of the nearly 20 million people living in New York State, about 12 million are assumed to be affected largely by heavy rains, 4 million by freezing rain and ice, and about 4 million by snow. This weather-affected population (individuals) translates into about half of the above-quoted numbers as electric grid customers (households or businesses), with 6 million electric grid customers affected by heavy rain, 2 million affected by freezing rain and ice, and about 2 million affected by snow. About 95 percent of these customers in each of the precipitation categories are connected by wire (cable), wireless services, or both.

While there may be some urban flooding in the rain band, this assessment focuses on electric grid and telecommunications outages. Thus, the analysis largely examines the approximately 2 million New York customers in the ice band and the approximately 2 million customers in the snow band.

There are an estimated 4.1 million utility poles along about 145,000 pole miles in New York State,[11] i.e., an average of about 28 poles per pole-mile. Nearly one-third (almost 1.4 million poles) would fall into each of the three precipitation zones. This implies, on average, about 0.7 poles per customer in the less populated ice and snow bands and only slightly more than 0.2 poles per customer in the metropolitan area of the rain band, which, at least in New York City, has a large portion of the electric wires and phone lines running underground. These are average numbers, and the local values of poles per customer may vary in inverse relation to the population density, with more poles per person in less densely populated areas. Therefore, on average, rural customers have a higher chance of wire line problems from snow and ice loads than do city dwellers. Of course, if an urban area is struck by power outages, each outage can affect a much larger number of customers.

But because of the much longer average wireline per rural customer, and the assumed rate of ice and snow load failure is proportional to wire length (although other factors, such as proximity to trees and wind exposure, play a considerable role), rural customers can expect longer restoration times. Another factor is that utilities may decide to bring back the largest possible number of customers at the earliest possible time with the finite number of repair crews available. For this reason, there is a tendency to make restoring lines with a high customer density a higher priority. This may leave rural areas at a lower priority, not by intent but for technical reasons. The pattern of restoration often starts from the core of the network and radiates outward from there. Also, telecommunications companies generally follow the electric grid restoration, and hence the pace and pattern of electric grid restoration largely controls the pace and pattern of telecommunications restoration.

The Public Service Commission monitors restoration plans on a regular basis and works with utility companies via post-storm reviews to improve restoration planning and performance. This information is also important for updating emergency response and assistance readiness.

The electric grid outage rate during the 2008 ice storm left about 12.4 percent of customers without power (see section 10.3.1). The percentage varied from county to county and from township to township, affecting between a few percent of customers up to almost 60 percent of customers (with the largest outages in rural Otsego County, which has a population density of only five people per square mile). The 2008 ice storm was centered on Albany County. There, it had a (radial) ice thickness that rarely exceeded 1 inch.

This analysis considers an ice storm with 1 to 2 inches of radial ice accumulation, which raises the average outage to 25 percent of customers, notwithstanding the possible strong local deviations from this average. This would imply that within the ice band a total of some 500,000 New York State customers would be without power. Fewer customers would probably be without power in the snow zone. Most customers without electricity are likely to lose communication services sooner or later due to dropped wirelines placed on the same poles as electric lines; from the inability to sustain back-up power at central phone offices when they run out of fuel; from drained batteries that cannot be recharged in customers' wireless home sets or in their wireless phones; or from drained batteries, inside the customers' homes, located at the end of fiber-optic drop lines.

Exhausted batteries in fiber loop converters that serve wireless cell sites could also contribute significantly to the loss of wireless communication. Typically, a single fiber loop converter serves all the wireless carriers at a tower. If one of the carriers cannot get generator power to the fiber loop converter, the sites of all carriers go down at the tower.

Restoration Times

Estimates of likely restorations for power and communication services are based on the recent storms described in Section 10.3.1 of this chapter regarding reported power failure and restoration times, including those times given for the 1998 Canada/United States ice storm and the December 2008 New York ice storm centered on Albany. This scenario also assumes that the ice thickness is greater than the ice thickness in two out of the three ice storms described, and that adjacent states are also affected by the scenario ice storm and, thus, need some of their utility repair crews to restore their own outages.

Restoration Time Estimates

Based on the assumptions above, the estimated restoration times for the central ice band are as follows:

- Ten percent of customers who lost power will have their electricity restored within 24 hours after the ice stops accumulating (i.e., the first 50,000 of the half million customers in the band of freezing rain/ice).
- Fifty percent of customers will have electricity restored after 10 days (i.e., 250,000 customers).
- Ninety percent of customers will have their power restored after three weeks (i.e., 450,000 of the half million customers in the band of freezing rain/ice).
- Full restoration of power will take about five weeks (i.e., for the remaining 10 percent, or 50,000 customers, who are most likely located in remote, rural locations).

The restoration times in the snow zone may be slightly shorter than in the ice band. From the trends and historic cases described earlier, it is likely that the majority of customers in most of the larger cities (e.g., Albany, Binghamton, and the Schenectady area in the freezing-rain zone, and Buffalo, Rochester, Syracuse, Ithaca, and Utica in the snow zone) will be part of the first 50 percent of customers who lost power to have it restored, i.e., within the first 10 days.

However, large uncertainties exist, and local restoration times may depend, in part, on how well prepared a utility is to cope with the consequences of the storm. Preventive tree trimming, stocking poles and wires, and arranging for outside crews to assist in the restoration can all make a difference, either by reducing the failure rate or by shortening restoration times. Tree trimming is unpopular with many homeowners, and in some areas utilities have succumbed to political pressure and reduced the clearance they ordinarily would maintain.

Economic and Social Impacts: Productivity Losses, Damage, and Equity and Environmental Justice Issues

To estimate economic productivity and damage losses, the case study uses the number of people affected and the number of customers restored per number of days until restoration from the previous section. It also uses 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).

Loss Estimates

Based on these assumptions, the losses to the state's economy are 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.

In addition to costs associated with lost productivity, costs associated with direct damages must be included as well (e.g., spoiled food; damaged orchards, timber, and other crops; replacement of downed poles and electric and phone/cable wires; medical costs; emergency shelter costs). These costs are likely to be of the same order as those of the productivity losses, which would imply a total ice storm cost of about $2 billion in New York State. This estimate does not include the snow effects on the state's economy and potential economic losses in the areas covered by snow. The loss estimate of $2 billion is probably on the low side, given that the 1998 ice storm resulted in losses of about U.S. $5.4 billion in Canada alone.

Equity and Environmental Justice Issues

The equity and environmental justice analysis uses the October 2006 snow storm in western New York as a historical analogue for illustrating potential social vulnerabilities during the recovery and restoration phase. The case considers rural areas and particular segments of the population who might be especially vulnerable during a protracted recovery. A primary advantage of analyzing this event instead of the 1998 ice storm is that the 2006 storm reflects a more current state of telecommunications technology. Its similarity to other severe ice storms is confirmed by one company's report that the degree of infrastructure damage and the magnitude of the company's response for the 2006 storm were comparable to those of the historic 1998 ice storm. Also, the 2006 storm triggered a recovery lasting nearly a month (NYSDPS, 2007), which is comparable with the estimates for restoration in this case study.

Following the 2006 storm event, the New York State Public Service Commission published a report detailing the steps leading up to the infrastructure failures and the subsequent difficulties in diagnosing problems and restoring service (NYSDPS, 2007). The report did not explicitly address population vulnerabilities, but it does reveal the limits of one communication company's capacity to respond, and it suggests a number of areas where these limits could be differentially experienced across regions and groups.

Date	Opening Trouble Load	Incoming Troubles	Troubles Cleared	Repair Technicians
10/14/2006	7,004	6,539	1,305	278
10/15/2006	10,811	6,274	2,467	372
10/16/2006	11,774	4,155	3,192	453
10/17/2006	15,699	7,196	3,271	497
10/18/2006	17,373	5,473	3,799	497
10/19/2006	18,263	4,791	3,901	535
10/20/2006	19,947	4,479	2,795	509
10/21/2006	19,604	4,015	4,358	514
10/22/2006	19,100	2,896	3,400	519
10/23/2006	19,700	2,068	1,468	568
10/24/2006	20,368	5,307	1,639	589
10/25/2006	21,218	3,830	2,980	599
10/26/2006	20,674	3,191	3,735	617
10/27/2006	20,157	3,213	3,730	608
10/28/2006	18,965	2,726	3,918	606
10/29/2006	17,361	1,986	3,590	607
10/30/2006	15,397	2,064	4,028	614
10/31/2006	14,884	3,164	3,677	606
11/01/2006	14,121	2,713	3,476	603
11/02/2006	13,055	2,358	3,424	649
11/03/2006	11,652	1,844	3,247	772
11/04/2006	10,085	1,801	3,368	776
11/05/2006	8,290	1,009	2,804	758
11/06/2006	6,113	934	3,111	732
11/07/2006	3,995	1,826	3,944	675
11/08/2006	2,540	1,747	3,202	636
11/09/2006	1,779	2,133	2,894	629
11/10/2006	1,388	1,306	1,697	448
11/11/2006	1,034	968	1,322	287

Table 10.2 Daily opening trouble reports, incoming troubles, troubles cleared, and staffing levels for October 2006 snow storm

The majority of damage in 2006 (and large amounts in the 1998 ice storm) was to tens of thousands of drop wires to individual building units. Nearly 93,000 trouble reports (not all may indicate that customers are out of service) were registered over a three-week period, with the peak report load being reached nearly two weeks after the storm (**Table 10.2**). These reports are a guide to restoration activities, with extended lag times on customer response complicating such efforts. As the report notes, one reason for the widespread delays was that customers were unaware that they were responsible for reporting the outage or assumed that service would be restored in time with power. One could expect that customers with better access to communications and information or who were socially and geographically more connected would be in a better position to understand their personal responsibility and act on the situation. On the other hand, isolated or impaired individuals or those who were in disconnected households in rural areas would be at higher risk of lengthened hardship.

The New York State Department of Public Service (2007) report notes another key variable in delays to restoring service: Large numbers of affected customers may have lost the incentive to promptly report outages because they simply switched to cell phones or left their homes. Whether these individual cases of non-reporting might contribute to aggregate, systemic, communitywide misdiagnoses and delays is unclear. But it does raise the prospect of one group's coping strategies potentially exacerbating the vulnerability of less mobile or otherwise isolated individuals who are located within the same communities. The report found it credible, for instance, that use of cellular phones likely contributed to delays in the company's initial damage assessment, which is key to the above suggestion that it delayed the restoration of more vulnerable customers.

In all such emergencies, there remains one big issue: How do households in rural communities report a telephone outage when the telephone services are out?

Coping during Service Restoration

Initial concentration on centralized and reported infrastructure failures is a technically logical reaction to the magnitude of the problem, but one that inevitably favors more densely populated areas. In more general terms, restoration after an ice storm would happen first in urban areas and then in rural areas, with smaller, remote communities likely to be restored last. This pattern is reinforced by the relative inaccessibility of remote areas in the aftermath of a storm, which prevents service technicians from safely restoring lines, particularly when the latter are in unapproachable areas in backs of houses, as was noted in the 2006 storm. Both of these issues are pertinent since central New York is marked by wide variations in population density and rapid transitions between accessible urban areas and more isolated rural areas.

The ability to cope through the lifecycle of a power and telecommunications outage partly reflects access to diverse telecommunications and transport options. In the 2006 ice storm, large numbers of households did cope by leaving their homes or switching primarily to cell phones. (The cell phone network relies, however, entirely on the landline network, except for the wireless link from the tower to the mobile phone. The tower is typically connected to the network over landline facilities, so cell phone service can fail when the lines feeding the towers are damaged.) Both of these strategies (leaving homes and cell phone use) rely on physical mobility, wealth, and geographic integration. More wealthy, urban populations with access to public transportation, adaptive vehicles (e.g., sport utility vehicles, all-terrain vehicles), or affordable temporary housing are substantively more resilient than elderly, low-income, disabled, rural, or otherwise transport-disadvantaged populations.

Under some conditions, cell phones can become a coping mechanism even when other parts of the communication network are down. However, cell phone coverage varies across providers and regions, and most major companies have dead zones within parts of rural New York State. Furthermore, during localized power outages, rural households with access to power exclusively from the electric grid will be—for as long as the latter is down—unable to recharge their cell phones without supplemental solar or car phone chargers.

Special Considerations and Communication Needs

Individuals with cognitive and physical impairments are less likely to receive emergency messages and to correctly interpret the recommended actions. This vulnerability could be compounded by mismanaged or misleading information disseminated by telecom providers (or other institutions).

In 2006, providers struggled to communicate critical information regarding service restoration promptly and consistently to the local media. At times, communication with public institutions bypassed local officials on the town and village level, officials who arguably would have been best placed to spread emergency communications (NYSDPS, 2007).

Case Study Conclusions

In summary, the case study shows that with the current state of vulnerability of power and telecommunications systems to winter storms, interruption of these services in New York State can affect hundreds of thousands of customers for many weeks from a single event. The resulting business interruptions and direct losses combined tend to produce losses in the hundreds of millions of dollars. Services for remote rural customers are typically the last to be restored and pose social injustice and inequities, and in some cases life-threatening emergency conditions.

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http://www.govtech.com/gt/635218?id=635218&full=1&story_pg=1
http://www.oft.state.ny.us/News/FinalNYS2008GoalsandStrategies.pdf
http://redtape.msnbc.com/2006/12/why_cell_phone_.html
Case 09-M-0527 brought before the NYS PSC re the Universal Service Fund http://documents.dps.state.ny.us/public/MatterManagement/CaseMaster.aspx?MatterSeq=31654
http://www3.dps.state.ny.us/pscweb/WebFileRoom.nsf/web/B3C502B29ECB84FD85256DF1007 56D51/$File/doc4618.pdf?OpenElement
Variations in Broadband Availability; NYS Broadband Council. http://www.nysbroadband.ny.gov/assets/documents/Final_Broadband_Strategy_June2009.pdf
http://www.nielsenmobile.com/documents/WirelessSubstitution.pdf
http://www.cdc.gov/nchs/data/nhis/earlyrelease/wireless200905.htm
http://www.ntia.doc.gov/broadbandgrants/BTOPAward_IONHoldCoLLC_121709.pdf
http://en.wikipedia.org/wiki/December_2008_Northeast_ice_storm
http://www.fema.gov/news/newsrelease.fema?id=48163
http://www.associatedcontent.com/article/1428697/kentucky_storms_weather_cause_phone.html and http://www.kentucky.com/news/state/story/682579.html
Kentucky power outages 1/28/09: http://vielmetti.typepad.com/.a/6a00d8341c4f1a53ef010536ff9773970c-800wi]
http://www.aimclearblog.com/2008/04/11/massive-spring-blizzard-takes-out-duluth-internet-services-electricity/
http://www.fema.gov/news/newsrelease.fema?id=3538
http://raincoaster.com/2006/06/08/the-ice-storm-quebec-1998/
http://www.nytimes.com/1998/01/11/nyregion/us-declares-five-counties-disaster-area.html
http://www.greenspun.com/bboard/q-and-a-fetch msg.tcl?msg_id=001HBW
http://www.stanford.edu/~rjohari/roundtable/sewg.pdf
Bell South/Katrina: https://netfiles.uiuc.edu/akwasins/www/Intelec06_Katrina.pdf
http://news.vzw.com/news/2008/09/pr2008-09-16s.html
NYS Public Workshop on Utility Preparation, Response, and Recovery from the December 2006 Wind Storm (Docket No. U-070067). http://www.governor.wa.gov/news/2007-03-09_storm_workshop_summary.pdf

Annual frequency of outages vs. customers affected for US 1984 to 1997
https://reports.energy.gov/B-F-Web-Part3.pdf.
Open File Report on Black Out 2003:
http://www3.dps.state.ny.us/pscweb/WebFileRoom.nsf/Web/5FA2EC9B01FE415885256E69004D4C9E/$File/doc14463.pdf?
http://www.beyondpesticides.org/wood/pubs/poisonpoles/tables/table2.html
http://www.pcworld.com/article/159630/universal_chargers_to_finally_become_a_reality.html and http://reviews.cnet.com/8301-13970_7-10165603-78.html
http://www.arrl.org/
http://tsp.ncs.gov
http://www.iec.org/online/tutorials/ss7/index.asp

Appendix A. Stakeholder Interactions

The first ClimAID project stakeholder meeting for the Telecommunications sector was held in conjunction with the Transportation sector stakeholders on February 12, 2009. Following this initial meeting, a questionnaire was developed and sent to the stakeholders. The questionnaire highlighted information that would allow an assessment of the most important challenges posed by climate change.

ClimAID telecommunications infrastructure stakeholders were invited to comment on a chapter draft dated January 8, 2010. We acknowledge the thorough reviews by several stakeholders.

Stakeholder Questionnaire

NYS ClimAID: Telecommunications Survey for Information Covering the Entire State of New York (4/07/2009)

A. Commercial Power

1) How many a) office facilities (central offices, head-ends, mobile switch centers) and b) outside plant facilities (cell towers, controlled environmental vaults, fiber nodes, etc.) have back-up power generation? (Give both percentage and actual number for both a. and b.)
2) What portion of facilities with back-up power generation is provided by a) battery and b) generator, or c) some other type of back-up generation?
3) How long can facilities operate on back-up generation types identified in question 2?
4) What arrangements are in place to replenish backup generation fuel and supplies for extended commercial power outages?

B. Wireless Networks

5) How many transmitters/repeaters are a) singularly located on towers, and b) co-located on towers with other service providers? (Give both percentage and actual number for both a. and b.)
6) Do you expect the arrangements in question 5 to change significantly over the next 5 years? 10 years?
7) What portion of the backbone network interconnecting transmitters/repeaters to the mobile switching offices are comprised of the following facilities: a) wireless, b) telephone company, c) cable company, d) other service provider?
8) What portions of cable facilities are a) aerial and b) underground?

C. Wireline (cable TV, telephone) **Networks**

9) How much of the outside cable plant is a) aerial cable, and b) underground cable?
10) How much of the outside cable plant is a) copper cable, and b) fiber optic cable? (Give both percentage and actual miles for both 9. and 10.)

D. Climate Hazard Thresholds

11) Do outside plant facilities (towers, antennas, aerial cables) meet or exceed industry recommended standards for surviving maximum wind velocities (mph) and ice loading? What are these maximum limits?
12) How many a) office facilities (central offices, head-ends, mobile switch centers) and b) outside plant facilities (cell towers, controlled environmental vaults, fiber nodes, etc.) are located in FEMA-designated flood zones (according to FIRM maps)?
13) What restoration/contingency plans are in place to prevent or mitigate service interruptions if these facilities become inundated? Note: FIRM maps are web accessible by state/county from: http://msc.fema.gov/

Stakeholder Participants

Industry representatives:

- AT&T
- Cablevision Systems Corp.
- Frontier Communications
- Sprint Nextel
- T-Mobile
- Time-Warner Cable
- Verizon & Verizon Wireless
- The Cable Telecommunications Association of New York, Inc. (CTANY)
- National Grid

Government representatives:

- Department of Homeland Security (DHS)
- New York City Mayor's Office of Long Term Planning and Sustainability
- New York City Office of Emergency Management (NYCOEM)
- New York State Department of Environmental Conservation (NYSDEC)
- New York State Emergency Management Office (NYSEMO)
- New York State Energy Research and Development Authority (NYSERDA)
- New York State Public Service Commission (PSC)

[1] Based on http://www.bea.gov/regional/gsp/action.cfm and using the 2007 data for NYS's telecommunications and broadcasting industry; they yield for 2007 a 4 percent GSP contribution to the then $1.1 trillion gross state product.

[2] For updates see: http://www.broadband.gov/maps/availability.htm

[3] http://www.dps.state.ny.us/mission.html

[4] http://www.govtech.com/gt/635218?id=635218&full=1&story_pg=1

[5] http://www.oft.state.ny.us/News/FinalNYS2008GoalsandStrategies.pdf

[6] The 20-year recurrence period is inferred from the linear log-log relationship between annual frequency F of outage occurrence (for the entire United States) and number of affected customers N, i.e., $\log F = 4.4 - 0.77 \log N$.

[7] NYSDPS 2002 became the foundation for the Commission's proceeding of Case 03-C-0992 to improve telecommunications network reliability throughout the state, creating among other things requirements for geographic route diversity of critical interoffice traffic and stand-alone capability for remote switching facilities.

[8] MIMO is the use of multiple antennas at both the transmitter and receiver end to improve communication performance. It is one of several forms of smart antenna technology.

[9] These issues are addressed in the PSC's State Universal Service Proceeding (09-M-0527). A whitepaper on wired, cable, and wireless coverage in NY ("white-spots") was produced (Staff Report, issued 12/23/09 available from http://documents.dps.state.ny.us/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=09-M-0527).

[10] See Case 09-M-0527 brought before the NYSPSC re the Universal Service Fund to address related issues: see Staff Report of 12/23/2009, document 49 downloadable from: http://documents.dps.state.ny.us/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=09-M-0527 ; or from http://documents.dps.state.ny.us/public/MatterManagement/CaseMaster.aspx?MatterSeq=31654.

[11] http://www.beyondpesticides.org/wood/pubs/poisonpoles/tables/table2.html

Chapter 11

Public Health

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[4] Cary Institute of Ecosystem Studies
[5] Rutgers University

Contents

Introduction

Greenhouse gas emissions have already altered Earth's climate, and substantial global and regional climate changes over at least the next 100 years are virtually guaranteed. This will include continued warming, along with changing patterns of floods, droughts, and other extreme events. The consequences of these climate changes for public health in New York State are likely to be dramatic, particularly for people who are more vulnerable because of age, pre-existing illness, or economic disadvantage.

A range of potential health vulnerabilities related to climate change (Confalonieri et al., 2007; CCSP, 2008) are relevant to New York State, including the following:

- more heat-related deaths
- diverse consequences as a result of more intense rainfall and flooding events
- worsening air quality (due to increasing smog, wildfires, pollens, and molds) and related respiratory health impacts
- changing patterns of vector-borne and other infectious diseases
- risks to water supply, recreational water quality, and food production due to shifting precipitation patterns

The first four of these issues are the focus of this chapter, which presents both public health vulnerabilities and adaptation options available for reducing future climate-related risks. The ClimAID health assessment has been carried out through a combination of research, analysis, and interactions with relevant New York State stakeholders. The broader interdisciplinary, multi-sector ClimAID team also contributed to this sector's work. Case studies highlight the interplay of risks and responses for key health outcomes.

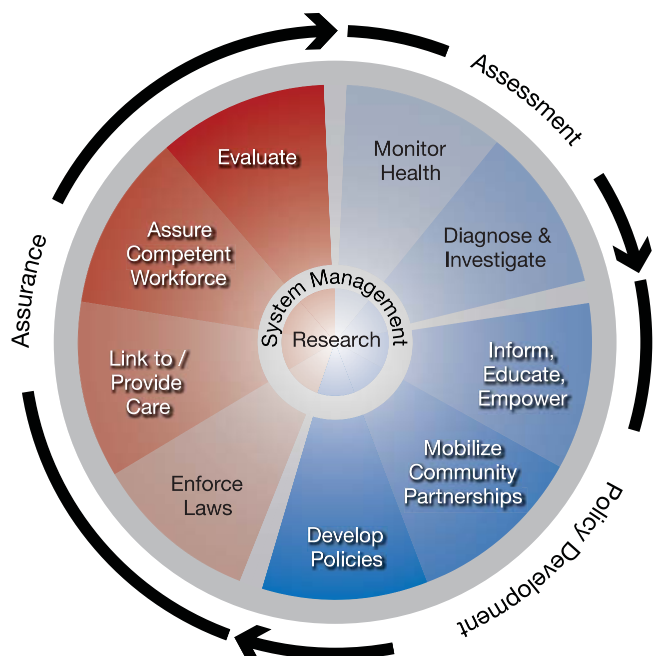
11.1 Sector Description

An overview of the public health system of New York State is essential for understanding potential climate change vulnerabilities as well as opportunities for increased resilience.

11.1.1 New York State Public Health System

The New York State public health infrastructure adheres to the Centers for Disease Control and Prevention's (CDC's) 10 essential public health services and core functions of assessment, policy development, and assurance of services (**Figure 11.1**). A diverse state, with populations spread unevenly over urban and rural service areas, New York is one of 26 states that rely primarily on a county-based system for public health service delivery (NYSPHC, 2003).

Local health departments operate under the authority of either the county legislature or local board of health. The result is a highly decentralized system with a non-uniform provision of core services. For example, local health departments provide environmental health services in 37 out of New York's 62 counties, while the State Department of Health (NYSDOH) provides service to the other areas (PHANYC, 2001). The New York State Public Health Council has identified this decentralization of public health service delivery as a key obstacle to efficient coordination of programming and data resources for climate-health preparedness. The Council has recommended regional, multi-county initiatives, which are proven models for more efficient and equitable distribution of expertise and services (NYSPHC, 2003).



Source: CDC

Figure 11.1 Core functions and 10 essential services of public health

In an effort to improve healthcare provision, in 1996 New York State initiated a data and knowledge communication program linking a wide range of partners, including hospitals, local health departments, nursing homes, diagnostic centers, laboratories, insurance provider networks, and federal agencies. Current communication networks—the Health Alert Network (state and city levels), the Health Provider Network, and the Health Information Network—are viewed as "both very helpful and very underutilized" by the Public Health Association of New York City (PHANYC, 2001). However, as a result of non-standardized data systems, the value of these networks across user groups is often compromised (PHANYC, 2001). These would be appropriate organizations to target for climate-health educational outreach and to evaluate climate-health interventions.

11.1.2 New York City Public Health System

New York City has been at the forefront of public health programming and policy since the founding of the Board of Health in 1866, the first such agency in the United States. More recently, New York City conducted the nation's first regional Health and Nutrition Examination Survey (NYC HANES), modeled after the CDC's National Health and Nutrition Examination Survey, providing policymakers and public health professionals with invaluable population-based health information (NYC DOHMH, 2007).

In 1995, the New York City Department of Health and Mental Hygiene (DOHMH) instituted a system of syndrome-based surveillance to locate potential disease outbreaks through ongoing monitoring of public health service use patterns and analysis for time- and location-related deviations. What started primarily as a means to detect waterborne illnesses that cause diarrhea through tracking influenza-like symptoms has evolved into electronic reporting of diverse health-related data. It now incorporates city emergency departments, pharmacy and over-the-counter medication purchases, employee absenteeism, and ambulance dispatch calls (Heffernan et al., 2004). With 39 city emergency departments participating, the electronic surveillance system covered about 75 percent of annual emergency department visits in its first year of operation alone (Heffernan and Mostashari et al., 2004).

11.1.3 Public Health Funding: Sources and Targets

Local health departments are funded by a combination of federal and state income streams and grants, complemented by fees levied through the local tax base and distributed by the State in proportion to county population. According to the Public Health Association of New York City (PHANYC), in 2001, New York City accounted for 46 percent of State aid, with the next six largest counties (Suffolk, Nassau, Erie, Westchester, Monroe, and Onondaga) receiving an additional 22 percent. Together these most-populous counties, which contain 72 percent of the state's population, accounted for 70 percent of the State aid to local health departments (PHANYC, 2001). In the 2001 fiscal year, the New York City Department of Health and Mental Hygiene budget drew 62 percent of funding from city tax revenues (PHANYC, 2001).

There is growing concern among public health practitioners that the confluence of State budget tightening with increasing needs of emerging chronic illnesses and emergency programming may threaten provision of basic healthcare services—both climate and non-climate related (NYS ACHO, 2008). While post-September 11 federal funding for emergency preparedness programming has benefitted the entire state and many aspects of surveillance and programming, the sufficiency and security of these funds into the future is a matter of serious concern (NYSPHC, 2003). It is also important to note that the federal health care landscape is evolving in significant ways as a result of the recent passage of health care reform legislation.

11.1.4 Emergency Preparedness

Projected changes in frequency and severity of extreme weather events will call upon the emergency preparedness plans within New York State. The New York State Disaster Preparedness Commission, made up of 23 State agencies and the American Red Cross, is responsible for disaster planning as well as communications with all levels of local, state, and federal-related bodies. The attacks of September 11 highlighted both strengths and gaps in New York City's public health infrastructure and underscored the importance of preparedness for the state in general. Immediate responses demonstrated the coordination of multiple health agencies to quickly and effectively react to threats to the public health of the city (Rosenfield, 2002). Transfer of the Office of Emergency Management command center from the World Trade Center (a high-profile, vulnerable location) to its current location in Brooklyn was one of the lessons learned. Most important, the events made clear that investments in preparedness infrastructure benefit the daily operations and effectiveness of the public health system.

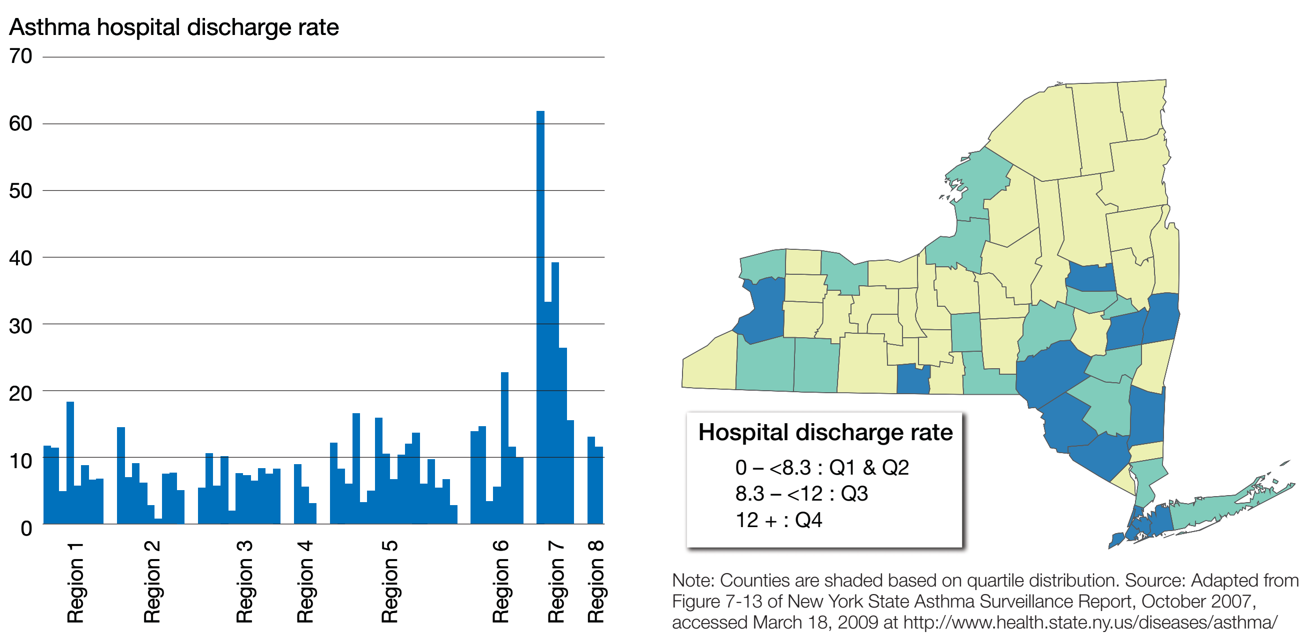
In 2002, Congress designated Centers for Disease Control and Prevention funding for nationwide capacity building and emergency response training initiatives and research through the Academic Centers for Public Health Preparedness program (Rosenfield, 2002). Columbia University in New York City was one of these centers and continues to provide valuable contributions in research and training to public health professionals through its National Center for Disaster Preparedness.

11.1.5 Current Health Status for Climate-sensitive Diseases

People whose health is already compromised by pre-existing disease are likely to be among the most vulnerable to emerging climate impacts. This is likely to be the case for a wide range of disease types. We can also identify a subset of diseases that may be particularly climate sensitive, either because the existing burden of disease is especially high or because climate change could directly impact the incidence or severity of the disease. Here we highlight three broad disease categories—asthma, cardiovascular, and infectious diseases—that are likely to be particularly climate sensitive in New York State. These were selected based on the limited evidence that currently exists on climate change and health. However, we do not mean to imply that these are the only disease categories for which climate change is or will be relevant in New York State. Ongoing research and reassessment will be critical to identify and target emerging health risks.

Asthma

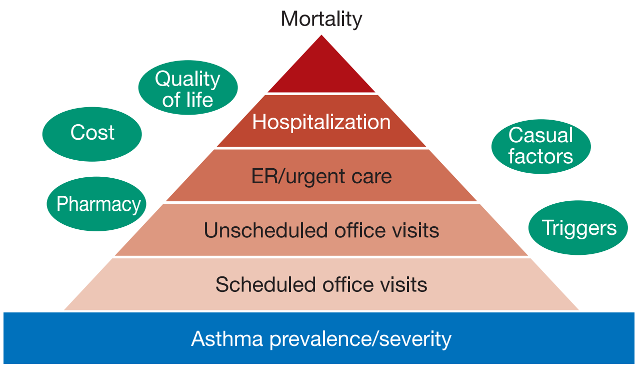
Asthma is potentially a climate-sensitive disease. It is already well established that asthma is exacerbated by certain weather patterns, pollen and mold seasons, and air pollution, and also is affected by indoor allergens like dust mites. Asthma can have allergic (such as pollen) or non-allergic (such as ozone) triggers, with the majority being of the allergic type. Many asthmatics are considered of mixed type, i.e., they are potentially sensitive to both types of triggers.



Note: Counties are shaded based on quartile distribution. Source: Adapted from Figure 7-13 of New York State Asthma Surveillance Report, October 2007, accessed March 18, 2009 at http://www.health.state.ny.us/diseases/asthma/

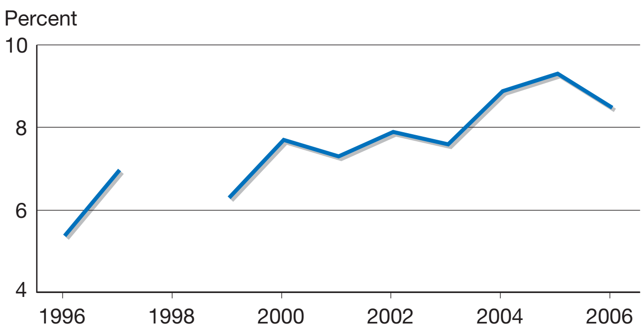
Figure 11.2 Hospital discharge rate for asthma per 10,000 population age 5 to14, 2005–2007 for (left) ClimAID regions (see Chapter 1, "Climate Risks," for definition of regions) and (right) for New York State counties

Childhood asthma is an important current health challenge in many parts of New York State—especially in the five counties that comprise New York City. Asthma events can be severe enough to require hospital admission (see **Figures 11.2** and **11.3**). However, the threshold of severity that triggers a hospital visit and admission likely differs by socioeconomic status. Wealthier individuals with health insurance, under doctor supervision, and with access to controller medications are less likely to have asthma attacks and are less likely to go to the hospital for care than are lower-income individuals lacking these resources.



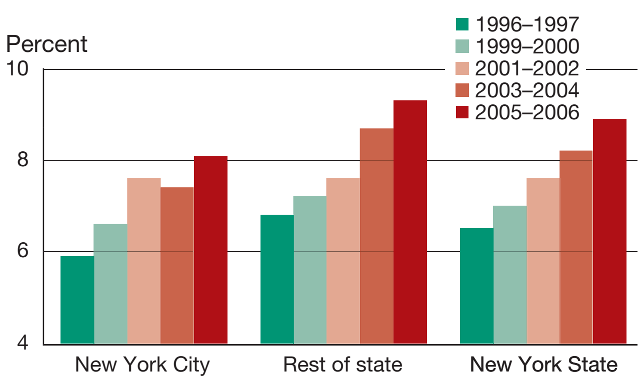
Source: Figure 3-1 of New York State Asthma Surveillance Report, October 2007, accessed March 18, 2009 at http://www.health.state.ny.us/diseases/asthma/

Figure 11.3 Asthma surveillance pyramid



Source: Figure 5-1 of New York State Asthma Surveillance Report, October 2007, accessed March 18, 2009 at http://www.health.state.ny.us/diseases/asthma/

Figure 11.4 Prevalence of current asthma among adults: 1996-2006 in New York State



Source: Figure 5-2 of New York State Asthma Surveillance Report, October 2007, accessed March 18, 2009 at http://www.health.state.ny.us/diseases/ asthma/

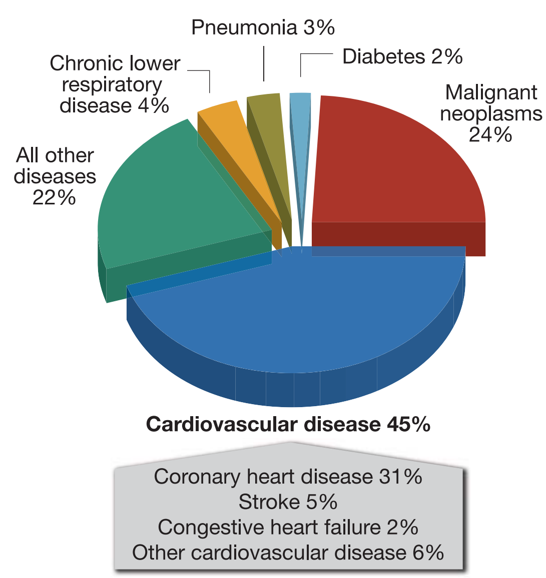
Figure 11.5 Prevalence of current asthma among adults, by region

Figure 11.4 shows that the percentage of New York State adults reporting that they currently have asthma that was diagnosed by a physician (based on survey methods) has trended generally upward between 1996 and 2006. In terms of prevalence as opposed to hospital admissions, New York City shows similar trends to the remainder of New York State (**Figure 11.5**).

Cardiovascular Disease

Cardiovascular disease is the leading cause of death in New York State (**Figure 11.6**). Underlying cardiovascular disease can interfere with a body's ability to regulate temperature in response to heat stress and, thus, can be an important predisposing factor for vulnerability to heat-related deaths. In addition, air pollution is a risk factor for cardiovascular disease (Kheirbek et al., 2011).

Cardiovascular disease is composed of several disease conditions, the most prevalent of which is coronary heart disease. Coronary heart disease, which is the single-greatest killer of New York State residents, occurs



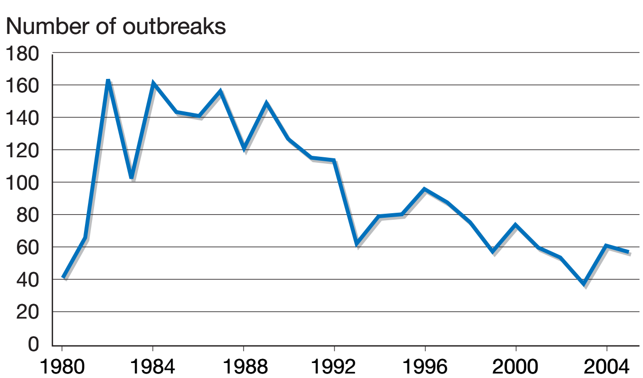
Source: New York State Vital Statistics, 1999

Figure 11.6 New York State causes of death due to thickening and hardening of arteries, resulting in insufficient blood supply and potentially severe damage to heart tissue and other organ systems in the body. Age-adjusted coronary heart disease mortality for persons aged 35 and older in New York State is the highest in the nation, mostly due to coronary heart disease in persons 65 and older. Fortunately, however, there has been a steady reduction in cardiovascular death rates in the state, from the 1979 level of about 600 per 100,000 residents to the 1999 level of less than 400 per 100,000 residents (Fisher et al., 2000).

Infectious Diseases

Infectious diseases were the most important health challenge in New York City during the 1800s and were the prime focus of the New York City Department of Health activities starting in 1866. The advent of antimicrobial drugs in the 1900s strongly reduced the burden of infectious disease. However, the end of last century and the early part of this century have seen the emergence and re-emergence of infectious pathogens in New York State and globally. Climate-sensitive infectious diseases include those spread by contaminated food (**Figure 11.7**) and water as well as those transmitted by insects and other vectors.

New York State has experienced the emergence of several vector-borne diseases in the past few decades. For instance, the state leads the nation in numbers of Lyme disease cases. Between 2002 and 2006, the top two counties in the United States for number of cases,



Source: Adapted from Figure 1 of Foodborne Disease Outbreaks in New York State, 2005, NYS DOH, Bureau of Community Environmental Health and Food Protection, January 2005; accessed March 19 2009 at http://www.health.state.ny.us/statistics/diseases/foodborne/outbreaks/2005/ report.htm

Figure 11.7 Reported food-borne disease outbreaks in New York State, 1980–2005

and four of the top 10 counties in Lyme disease incidence rate (cases per 100,000 people) were in New York State. Illness caused by West Nile virus in the state peaked in 2002 at 82 cases, and the state has had the highest numbers of cases on the East Coast since 2005. Both Lyme disease and West Nile virus tend to be most prevalent in the Hudson Valley, Long Island, and New York City areas with dense and growing human populations. The factors responsible for the concentration of Lyme disease and West Nile fever in the southeastern region of the state are not well understood. Similar southeastern concentrations of *Borrelia burgdorferi*-infected blacklegged ticks, as well as of West Nile virus in mosquitoes and wild birds, suggest that ecological conditions, possibly including warmer climate, might be important.

11.1.6 Economic Value

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 New York State full- and part-time employment in health care and social assistance for 2008 was 1,486,598 (New York State Department of Labor, 2008). The 2008 current dollar state GDP was $1.144 trillion; of this total, more than $82 billion was in the public health sector (U.S. Department of Commerce Bureau of Economic Analysis, 2009). (See also the ClimAID economic analysis in Annex III to the full report.)

11.2 Climate Hazards

Climate factors and measures that are particularly relevant to the health of New Yorkers are highlighted and briefly introduced below. Some of these factors are discussed in more detail in Vulnerabilities and Opportunities (Section 11.3) and in case studies at the end of the chapter.

11.2.1 Temperature

Historical observations over the past 40 years provide clear evidence of increasing average temperatures in New York State. Projected increases in average temperatures in the coming decades will also be associated with increases in other temperature measures, such as the minimum and maximum temperature and the minimum, average, and maximum daily apparent temperature (perceived outdoor temperature, including factors such as wind and humidity, as well as air temperature). Other temperature measures of relevance to public health include the number of days with temperature exceeding 85, 90, and 95°F, all of which are projected to increase. Consequently, heat-related mortality could increase, and persons with heat-sensitive conditions are at particular risk.

As temperature increases, and with potential increases in the frequency of stagnant air events over New York State, conditions favoring high ozone days could increase. Daily maximum 8-hour ozone concentrations and the number of days with 8-hour ozone concentrations above 60–70 parts per billion (ppb) represent useful measures of changing ozone-related risks for respiratory irritation and damage. These risks are particularly relevant for people working or exercising outdoors, including children and those with respiratory disease.

11.2.2 Precipitation

Extreme precipitation and flooding events can have significant direct health impacts due to injury and drowning, and can have a wide range of indirect impacts such as diminished water and food supply and quality, interruption of healthcare service delivery, mental health consequences, and respiratory responses to indoor mold. The most relevant precipitation metrics are not yet known and will likely vary for different health-related outcomes. Research is needed to elucidate the links between precipitation metrics and health in New York State.

11.2.3 Changing Patterns of Monthly Temperatures and Precipitation

Average temperature and precipitation pattern shifts can impact ecosystems (see Chapter 6, "Ecosystems") and can affect vector habitats and prevalence. West Nile virus as well as other diseases carried by mosquitoes, ticks, or other vectors could change their distribution or pattern of occurrence. In addition, allergy triggers such as pollen and molds could change in timing and intensity.

11.3 Vulnerabilities and Opportunities

Climate change vulnerabilities in the public health sector are, to a large extent, ones in which public health and environmental agencies are already engaged. However, climate change places an additional burden on public health agencies that are already burdened by low levels of staffing and funding. Climate-related risk factors include heat events, extreme storms, disruptions of water supply and quality, decreased air quality, changes in timing and intensity of pollen and mold seasons, and alterations in patterns of infectious disease vectors and organisms. Climate-sensitive health vulnerabilities include heat-related mortality (death) and morbidity (illness), respiratory disorders stemming from aeroallergen and/or air pollution exposures, trauma and complex downstream effects related to storm events, and a range of infectious diseases.

In later sections of this chapter, we present case studies to highlight a subset of health vulnerabilities for New York State over coming decades for which adequate information and expertise currently exists to make qualitative or in some cases quantitative assessments. The case studies examine health impacts related to heat, ozone, extreme storms, and West Nile virus. These were chosen as examples based on the current (albeit limited) knowledge base, and should not be viewed as a complete list of future health vulnerabilities for New York State. Evolving science and experience will continue to clarify the picture of health vulnerabilities in coming years. In the present section, our goal is to provide a broad sense of the range of potential health vulnerabilities.

Information on public health vulnerabilities to climate variability and change in New York State is available from a series of assessments carried out over the past decade, including the Metropolitan East Coast Climate Impact Assessment (Rosenzweig and Solecki, 2001), the New York Climate and Health Project (www.globalhealth.columbia.edu/projects/RES0716289.html), and the Northeast Climate Impact Assessment (Frumhoff et al., 2007). Based on an assessment of this and subsequent work, a review of current health challenges in New York State, and on our engagement with stakeholders, several climate-related health vulnerabilities emerged. These include increased risk for all natural-cause mortality associated with more frequent and severe heat waves (Knowlton et al., 2007; Kinney et al., 2008), asthma exacerbations and mortality associated with ozone air pollution (Knowlton et al., 2004), allergy and asthma associated with altered pollen and mold seasons, water- and food-borne diseases, emergence and/or changing distributions of vector-borne diseases, and impacts of extreme storm events, especially coastal storms in the New York City metropolitan area and Long Island.

These vulnerabilities span a range from the relatively direct, data-rich, and well-understood to more complex, multi-factorial systems for which both data and models are currently underdeveloped. Even the direct and relatively well-studied effects of heat waves on mortality among the urban elderly and those with low incomes require further work to assess potential future impacts of climate change against a backdrop of changing economics, energy constraints, demographics, and adaptation responses (Kinney et al., 2008).

Uncertainties pervade any effort to predict either direct or indirect health impacts of climate change. These uncertainties relate to projections of site-specific climate change itself, due to uncertain future pathways of global greenhouse gas emissions and the behavior of the climate system in response. This complicates future projections of climate metrics, including temperature, sea level rise, and the effects of changing temperature and humidity on health outcomes like communicable and vector-borne diseases. Additional uncertainties arise in projecting future health impacts due to potential future pathways of population demographics, economic development, and adaptation measures. These multiple uncertainties increase the importance of building resilience into the public health system to cope with inevitable surprises to come. Vulnerability assessments combined with a full accounting of uncertainties will help in prioritizing climate-health preparedness plans, informing communities on which actions should be taken first, and which information gaps are most critical to fill.

11.3.1 Temperature-Related Mortality

Extreme temperature events have been linked with higher mortality rates and premature death, in particular among vulnerable populations (elderly, young children, or those suffering from cardiovascular or respiratory conditions) (WHO, 2004; Basu and Ostro, 2009). More than 70,000 deaths were associated with the heat wave in Western Europe during the summer of 2003 (Robine et al., 2008). In the United States, mortality rates from higher than normal temperatures have also been documented, with approximately 10,000 deaths during the summer of 1980 (Ross and Lott, 2003). Large metropolitan areas where the heat-island effect is prevalent are particularly affected. It has been estimated that in Chicago, between 600 (Dematte, 1998) and 739 (Klinengberg, 2002) people died during the July 1995 heat wave, and an additional 80 cases were attributed to a second extreme heat episode during the summer of 1999. Similarly, 118 died in Philadelphia during the July 6–14, 1993 heat wave. Moreover, the combined effects of extreme temperature and air pollution have been seen to increase morbidity and mortality cases during heat waves (Cheng, 2005).

There is also emerging evidence for effects of heat on hospital admissions for respiratory and cardiovascular diseases. For example, in a study of summertime hospital admissions in New York City during the period from 1991 to 2004, Lin and colleagues (2009) from the NYSDOH found significant associations between high temperatures and increased risk of both respiratory and cardiovascular admissions. While effects were seen throughout the population, elderly and Hispanic residents appeared to be especially vulnerable.

Those at higher risk for heat-related health effects are among the most vulnerable urban residents: the elderly, those with low incomes, those with limited mobility and social contact, those with pre-existing health conditions and belonging to nonwhite racial/ethnic groups, and those lacking access to public facilities and public transportation or otherwise lacking air conditioning. Children, urban residents, and communities in the northern parts of the state that are not adapted to heat may also be vulnerable subgroups for temperature-related mortality (death) and morbidity (illness). As stated earlier, cardiovascular disease can impair a body's ability to regulate temperature in response to heat stress and thus can be an important predisposing factor for vulnerability to heat-related deaths. Further, persons with cardiovascular disease are often under close medical supervision and care, and thus may be especially vulnerable to disruptions of health care access following extreme storm and flood events. Since physical activity reduces the risk of cardiovascular disease, changing patterns of physical activity due to climate change could impact disease in either positive or negative directions.

As a result of climate change, New York State will experience increased temperatures that could have significant health consequences. Climate change is shifting the overall temperature distribution in the United States such that extreme high temperatures will become hotter. This will change the timing of heat waves and also increase their frequency. Urban areas are especially vulnerable because of the high concentrations of susceptible populations and the influence of the urban heat island effect. Thus, preparing for and preventing heat-related health problems is likely to be of growing importance in urban areas. Health departments, city planners, and emergency response agencies all can benefit from assessments aimed at determining future heat/health vulnerabilities under a changing climate. While the largest changes may lie 50 to 100 years in the future, smaller but still health-relevant changes are likely to occur over time horizons of interest to planners, e.g., 20 to 30 years. However, to be useful, future projections should take account not only of climate change, but also changes in population characteristics, infrastructure, and adaptive measures.

In a relevant recent study, Knowlton et al. (2007) examined potential climate change impacts on heat-related mortality in the New York City metropolitan area. Current and future climates were simulated at a 36-kilometer grid scale over the northeastern U.S. with a global-to-regional climate modeling system. Summer heat-related premature deaths in the 1990s and 2050s were estimated using a range of scenarios and approaches to modeling acclimatization. Acclimatization describes physiological adaptation in the human body that allows for maintenance of normal body temperature range during heat exposure through increased evaporative cooling (sweating), thereby mitigating cardiovascular system stress. Projected regional increases in heat-related premature mortality by the 2050s ranged from 47 to 95 percent, with a mean 70 percent increase as compared to the 1990s. Acclimatization reduced regional increases in summer heat-related premature mortality by about 25 percent. Local impacts varied considerably across the region, with urban counties showing greater numbers of deaths and smaller percentage increases than less urbanized counties. While considerable uncertainty exists in climate forecasts and future health vulnerability, the range of projections developed suggested that by mid-century acclimatization may not completely mitigate the effects of temperature change in the New York metropolitan region, resulting in an overall net increase in heat-related premature mortality.

It is important to note that more people die on average in winter than in summer in New York State and in the United States as a whole. However, winter mortality is heavily influenced by influenza and other viral infections, which are more prevalent during the winter season, likely due to low indoor and outdoor humidity and activity patterns. Temperature per se appears to play a minor role. Thus, it appears unlikely that climate warming will significantly reduce winter mortality in the foreseeable future. To examine this issue further, we present below a new case study of the impacts of daily temperature throughout the year on daily mortality due to all natural causes in New York County (i.e., Manhattan). We first fitted the U-shaped exposure-response function linking temperature with mortality over the full year using an 18-year record of daily observations. The analysis controlled for seasonal and day-of-week cycles in the data. We then used the fitted function to compute future mortality under the alternative climate models and scenarios included in the ClimAID project. While temperature-related mortality was projected to diminish slightly in winter under climate change, increases in warm-season mortality far outweighed this benefit in all cases. Further, we noted that, on a percentage basis, future mortality increases will be most prominent in the spring and fall seasons.

11.3.2 Air Pollution and Aeroallergens

Climate variables such as temperature, humidity, wind speed and direction, and mixing height (the vertical height of mixing in the atmosphere) play important roles in determining patterns of air quality over multiple scales in time and space. These linkages can operate through changes in air pollution emissions, transport, dilution, chemical transformation, and eventual deposition of air pollutants. Policies to improve air quality and human health take meteorologic variables into account in determining when, where, and how to control pollution emissions, usually assuming that weather observed in the past is a good proxy for weather that will occur in the future, when control policies are fully implemented. However, policymakers now face the unprecedented challenge presented by changing climate baselines. Air quality planning is a very important function of the New York State Department of Environmental Conservation, which is charged with the difficult task of developing and implementing strategies to achieve air quality standards despite being downwind of several states that host major emission sources.

There is growing recognition that development of optimal control strategies to control future levels of key health-relevant pollutants like ozone and fine particles ($PM_{2.5}$)* should incorporate assessment of potential future climate conditions and their possible influence on the attainment of air quality objectives. Given the significant health burdens associated with ambient air pollution, this is critical for designing policies that maximize future health protection. Although not regulated as air pollutants, naturally occurring air contaminants of relevance to human health, including smoke from wildfires and airborne pollens and molds, also may be influenced by climate change. Thus there is a range of air contaminants, both anthropogenic and natural, for which climate change impacts are of potential importance.

In spite of the substantial successes achieved since the 1970s in improving air quality, many New Yorkers continue to live in areas that do not meet the health-based National Ambient Air Quality Standards for ozone and $PM_{2.5}$ (www.epa.gov/air/criteria.html). Ozone is formed in the troposphere mainly by reactions that occur in polluted air in the presence of sunlight. The key precursor pollutants for ozone formation are nitrogen oxides (emitted mainly by burning of fuels) and volatile organic compounds (VOCs, emitted both by burning of fuels and evaporation from stored fuels and vegetation). Because ozone formation increases with greater sunlight and higher temperatures, it reaches unhealthy levels primarily during the warm half of the year. Daily peaks occur near midday in urban areas, and in the afternoon or early evening in downwind areas. It has been firmly established that breathing ozone can cause inflammation in the deep lung as well as short-term, reversible decreases in lung function. In addition, epidemiologic studies of people living in polluted areas have suggested that ozone can increase the risk of asthma-related hospital visits and premature mortality (Peel et al., 2005; Peel et al., 2007; Kinney et al., 1991; Levy et al., 2005). Vulnerability to ozone effects on the lungs is greater for people who spend time outdoors during ozone periods, especially those who engage in physical exertion, which results in a higher cumulative dose to the lungs. Thus, children, outdoor laborers, and athletes all may be at greater risk than people who spend more time indoors and who are less active. Asthmatics are also a potentially vulnerable subgroup.

$PM_{2.5}$ is a complex mixture of solid and liquid particles that share the property of being less than 2.5 μm (millionths of a meter) in aerodynamic diameter. Because of its complex nature, $PM_{2.5}$ has complicated origins, including primary particles emitted directly from a variety of sources and secondary particles that form via atmospheric reactions of precursor gases. $PM_{2.5}$ is emitted in large quantities by combustion of fuels by motor vehicles, furnaces and power plants, wildfires, and, in arid regions, windblown dust (Prospero et al., 2003). Because of their small size, $PM_{2.5}$ particles have relatively long atmospheric residence times (on the order of days) and may be carried long distances from their source regions (Prospero et al., 2003; Sapkota et al., 2005). For example, using satellite imagery and ground-based measurements, Sapkota and colleagues tracked a wildfire plume over 621 miles (1,000 km) from northern Quebec, Canada, to the city of Baltimore, Maryland, on the East Coast of the U.S. (Sapkota et al., 2005). Research on health effects in urban areas has demonstrated associations between both short-term and long-term average ambient $PM_{2.5}$ concentrations and a variety of adverse health outcomes, including premature deaths related to heart and lung diseases (Samet et al., 2000; Pope et al., 2002; Schwartz, 1994). In addition, smoke from wildfires has been associated with increased hospital visits for respiratory problems in affected communities (Hoyt and Gerhart, 2004; Johnston et al., 2002; Moore et al., 2006). In a study of acute asthma emergency room visits in NYC, the pollutants most associated were ozone, sulfur dioxide and one-hour $PM_{2.5}$. A more robust health impact was observed for the daily maximum $PM_{2.5}$ concentration than the 24-hour mean, suggesting peak exposure may have larger health impacts (NYSERDA, 2006).

Airborne allergens (aeroallergens) are substances present in the air that, upon inhalation, stimulate an allergic response in sensitized individuals. Aeroallergens can be broadly classified into pollens (e.g., from trees, grasses, and/or weeds), molds (both indoor and outdoor), and a variety of indoor proteins associated with dust mites, animal dander, and cockroaches. Pollens are released by plants at specific times of the year that depend to varying degrees on temperature,

* PM2.5 is a complex mixture of solid and liquid particles that are less than 2.5 μm (millionths of a meter) in diameter.

sunlight, moisture, and CO_2. Allergy is assessed in humans either by skin prick testing or by a blood test, both of which involve assessing reactions to standard allergen preparations. A nationally representative survey of allergen sensitization spanning the years 1988–1994 found that 40 percent of Americans are sensitized to one or more outdoor allergens, and that prevalence of sensitization had increased compared with data collected in 1976–1980 (Arbes et al., 2005).

Allergic diseases include allergic asthma, hay fever, and atopic dermatitis. More than 50 million Americans suffer from allergic diseases, costing the U.S. healthcare system over $18 billion annually (American Academy of Allergy, Asthma, and Immunology, 2000). For reasons that remain unexplained, the prevalence of allergic diseases has increased markedly over the past three to four decades. Asthma is the major chronic disease of childhood, with almost 4.8 million U.S. residents affected. It is also the principal cause for school absenteeism and hospitalizations among children (O'Connell, 2004). Mold and pollen exposures and home dampness have been associated with exacerbation of allergy and asthma, as has air pollution (Gilmour et al., 2006; IOM, 2000; IOM, 2004; Jaakkola and Jaakkola, 2004).

The influence of climate on air quality is substantial and well established (Jacob, 2005), giving rise to the expectation that changes in climate are likely to alter patterns of air pollution concentrations. Higher temperatures hasten the chemical reactions that lead to ozone and secondary particle formation. Higher temperatures, and perhaps elevated carbon dioxide (CO_2) concentrations, also lead to increased emissions of ozone-relevant VOC precursors by vegetation (Hogrefe et al., 2005).

Weather patterns influence the movement and dispersion of all pollutants in the atmosphere through the action of winds, vertical mixing, and rainfall. Air pollution episodes can occur with atmospheric conditions that limit both vertical and horizontal dispersion. For example, calm winds and cool air aloft limits dispersion of traffic emissions during morning rush hour in winter. Emissions from power plants increase substantially during heat waves, when air conditioning use peaks. Weekday emissions of nitrogen oxides (NOx) from selected power plants in California more than doubled on days when daily maximum temperatures climbed from 75°F to 95°F in July, August, and September of 2004 (Drechsler et al., 2006). Changes in temperature, precipitation, and wind affect windblown dust, as well as the initiation and movement of forest fires.

Finally, the production and distribution of airborne allergens such as pollens and molds are highly influenced by weather phenomena, and also have been shown to be sensitive to atmospheric CO_2 levels (Ziska et al., 2003). The timing of phenologic events such as flowering and pollen release is closely linked with temperature.

Human-induced climate change is likely to alter the distributions over both time and space of the meterologic factors described above. There is little question that air quality will be influenced by these changes. The challenge is to understand these influences better and to quantify the direction and magnitude of resulting air quality and health impacts.

Hogrefe and colleagues were the first to report results of a local-scale analysis of air pollution impacts of future climate changes using an integrated modeling approach (Hogrefe et al., 2004a; Hogrefe et al., 2004b). In this work, a global climate model was used to simulate hourly meteorologic data from the 1990s through the 2080s based on two different greenhouse gas emissions scenarios, one representing high emissions and the other representing moderate emissions. The global climate outputs were downscaled to a 36-kilometer (22-mile) grid over the eastern U.S. using regional climate and air quality models. When future ozone projections were examined, summer-season daily maximum 8-hour concentrations averaged over the modeling domain increased by 2.7, 4.2, and 5.0 ppb in the 2020s, 2050s, and 2080s, respectively, as compared to the 1990s, due to climate change alone. The impact of climate on mean ozone values was similar in magnitude to the influence of rising global background ozone by the 2050s, but climate had a dominant impact on hourly peaks. Climate change shifted the distribution of ozone concentrations toward higher values, with larger relative increases in future decades occurring at higher ozone concentrations.

The finding of larger climate impacts on extreme ozone values was confirmed in a study in Germany (Forkel and Knoche, 2006) that compared ozone in the 2030s and the 1990s using a downscaled integrated modeling system. Daily maximum ozone concentrations increased by 2–6 ppb (6–10 percent) across the study region. However, the number of cases where daily maximum ozone exceeded 90 ppb increased by nearly four-fold, from 99 to 384.

More recently, the influence of climate change on $PM_{2.5}$ and its component species have been examined in the northeastern U.S., including New York State, using an integrated modeling system (Hogrefe et al., 2006). Results showed that $PM_{2.5}$ concentrations increased with climate change, but that the effects differed by component species, with sulfates and primary particulate matter increasing markedly but with organic and nitrated components decreasing, mainly due to transformation of these volatile species from the particulate to the gaseous phase.

The health implications of wildfire smoke have been tragically demonstrated by events in Russia during the summer of 2010. Because the risk of wildfire initiation and spread is enhanced with higher temperatures, decreased soil moisture, and extended periods of drought, it is possible that climate change could increase the impact of wildfires in terms of frequency and area affected (IPCC, 2007a; Westerling et al., 2006). Among the numerous health and economic impacts brought about by these more frequent and larger fires, increases in fine particulate air pollution are a key concern, both in the immediate vicinity of fires as well as in areas downwind of the source regions. Several studies have been published examining trends in wildfire frequency and area burned in Canada and the U.S. Most such studies report upward trends in the latter half of the 20th century that are consistent with changes in relevant climatic variables (Westerling et al., 2006; Gillett et al., 2004; Podur et al., 2002). Interpretation of trends in relation to climate change is complicated by concurrent changes in land cover and in fire surveillance and control. However, similar trends were seen in areas not affected by human interference (Westerling, et al., 2006) or under consistent levels of surveillance over the follow-up period (Podur et al., 2002). Several studies have looked at wildfire risk in relation to climate change (Lemmen and Warren, 2004; Williams et al., 2001; Flannigan et al., 2005; Bergeron et al., 2004).

Aeroallergens that may respond to climate change include outdoor pollens generated by trees, grasses, and weeds, and spores released by outdoor or indoor molds. Historical trends in the onset and duration of pollen seasons have been examined extensively in recent studies, mainly in Europe. Nearly all species and regions analyzed have shown significant advances in seasonal onset that are consistent with warming trends (Root et al., 2003; Beggs, 2004; Beggs and Bambrick, 2005; Clot, 2003; Emberlin et al., 2002; Galan et al., 2005; Rasmussen, 2002; Teranishi et al., 2000; van Vliet et al., 2002; World Health Organization, 2003). There is more limited evidence for longer pollen seasons or increases in seasonal pollen loads for birch (Rasmussen, 2002) and Japanese cedar tree pollen (Teranishi et al., 2000). Grass pollen season severity has been shown to be greater with higher pre-season temperatures and precipitation (Gonzalez et al., 1998). What remains unknown is whether and to what extent recent trends in pollen seasons may be linked with upward trends in allergic diseases (e.g., hay fever, asthma) that have been seen in recent decades.

In addition to earlier onset of the pollen season and possibly enhanced seasonal pollen loads in response to higher temperatures and resulting longer growing seasons, there is evidence that CO_2 rise itself may cause increases in pollen levels. Experimental studies have shown that elevated CO_2 concentrations stimulate greater vigor, pollen production, and allergen potency in ragweed (Ziska et al., 2003; Ziska and Caufield, 2000; Singer et al., 2005). Ragweed is arguably the most important pollen species in the U.S., with up to 75 percent of hay fever sufferers sensitized (American Academy of Allergy, Asthma, and Immunology, 2000). Significant differences in allergenic pollen protein were observed in comparing plants grown under historical CO_2 concentrations of 280 ppm, recent concentrations of 370 ppm, and potential future concentrations of 600 ppm (Singer et al., 2005). Interestingly, significant differences in ragweed productivity were observed in outdoor plots situated in urban, suburban, and rural locales where measurable gradients were observed in both CO_2 concentrations and temperatures. Cities are not only heat islands but also CO_2 islands, and thus to some extent represent proxies for a future warmer, high-CO_2 world (Ziska et al., 2003).

With warming over the longer term, changing patterns of plant habitat and species density are likely, with gradual movement northward of cool-climate species like maple and birch, as well as northern spruce (IPCC, 2007a). Although these shifts are likely to result in altered pollen patterns, to date they have not been assessed quantitatively.

As compared with pollens, molds have been much less studied (Beggs, 2004). This may reflect in part the relative paucity of routine mold monitoring data from which trends might be analyzed, as well as the complex relationships between climate factors, mold growth, and spore release (Katial et al., 1997). One study examining the trends in Alternaria spore counts between 1970 and 1998 in Derby, U.K., observed significant increases in seasonal onset, peak concentrations, and season length. These trends parallel gradual warming observed over that period.

In addition to potential effects on outdoor mold growth and allergen release related to changing climate variables, there is also concern about indoor mold growth in association with rising air moisture and especially after extreme storms, which can cause widespread indoor moisture problems from flooding and leaks in the building envelope. Molds need high levels of surface moisture to become established and flourish (Burge, 2002). In the aftermath of Hurricane Katrina, very substantial mold problems were noted, causing unknown but likely significant impacts on respiratory morbidity (Ratard, 2006). There is growing evidence for increases in both the number and intensity of tropical cyclones in the north Atlantic since 1970, associated with unprecedented warming of sea surface temperatures in that region (IPCC, 2007a; Emanuel, 2005).

Taken as a whole, the emerging evidence from studies looking at historic or potential future impacts of climate change on aeroallergens led Beggs to state (Beggs, 2004):

> [This] suggests that the future aeroallergen characteristics of our environment may change considerably as a result of climate change, with the potential for more pollen (and mold spores), more allergenic pollen, an earlier start to the pollen (and mold spore) season, and changes in pollen distribution.

11.3.3 Infectious Diseases

Infectious diseases that are transmitted by arthropod vectors, such as mosquitoes and ticks, are highly sensitive to climate change. Effects of even small increases in average temperatures can increase rates of population growth and average population densities of mosquitoes and other vectors (Harvell et al., 2002; Epstein, 2005). In addition, both the biting rates of mosquitoes and the replication rates of the parasites and pathogens they transmit increase with increasing temperatures (Harvell et al., 2002). Nevertheless, the degree to which recent and future climate change affects the distribution and intensity of vector-borne diseases remains controversial (Harvell et al., 2002; Ostfeld, 2009). One common criticism of the contention that climate warming will cause vector-borne diseases to spread geographically is that, just as some areas that are below the suitable temperature range will move into this range, others that are currently suitable might become too warm. Evidence to support this contention, however, is scant (Ostfeld, 2009). Moreover, because the overall climate of New York State appears to be well below any detectable upper thresholds for vector-borne disease, it seems that climate warming is more likely to increase, rather than decrease, the burden of vector-borne disease in the state.

In the case of Lyme disease, a climate-based spatial model (Brownstein, et al., 2005) suggested that the conditions under which blacklegged tick populations can be supported will expand northward into Canada as the climate warms. However, this model assumed that ticks currently occupy the entire state of New York and therefore was unable to make predictions relevant to the expansion of Lyme disease within the state. Other models (Ogden et al., 2005) also predict northward expansion of blacklegged ticks into areas currently assumed to be too cold to support them. These models are based on assumed, rather than empirically verified, relationships between temperature and tick demography (Killilea et al., 2008). In contrast, the relationships between specific climatic parameters and cases of West Nile virus illness or mosquito vector demography are better established. Therefore, this chapter focuses on West Nile virus in Case Study D.

11.4 Adaptation Strategies

Climate is often considered a factor that will change the frequency and severity of existing health problems more than create entirely new ones. From this point of view, the challenge is more about integrating specific information about climate-related vulnerabilities into ongoing programs of public health surveillance, prevention, and response than developing new programs to deal with unique challenges. While largely valid, this view misses the mark in one important way, namely that changing climate brings the possibility of entirely new health risks, for example from new infectious diseases or coastal storm events of unprecedented magnitude.

Here we briefly review a range of adaptation options that should be considered in addressing climate-related health risks in New York State.

11.4.1 Key Adaptation Strategies

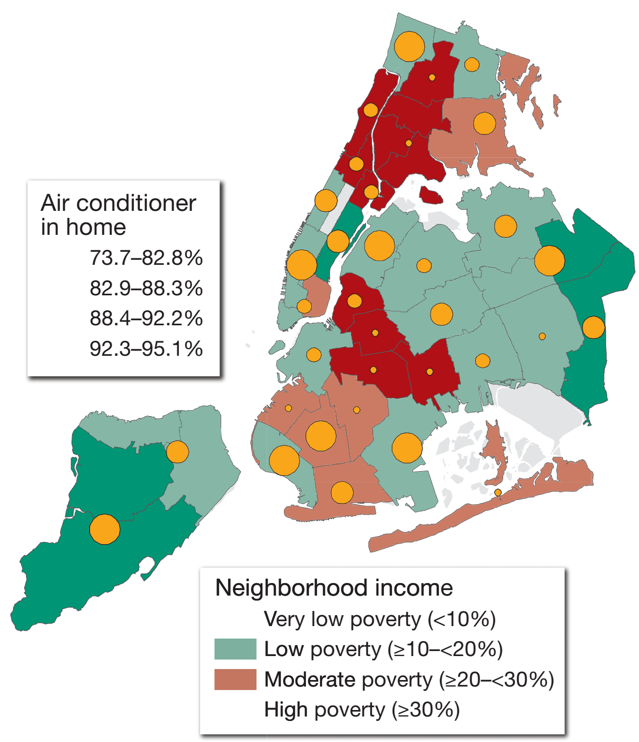
Avoiding or reducing the health impacts of climate change will ultimately depend on public health preparedness. In the sections that follow, a number of adaptations, or preparedness strategies, are discussed.

Heat Adaptation

Heat-related mortality has been recognized as an important public health challenge for many decades. As a result, heat warning and response systems have been implemented in many cities in the United States and Europe, including New York City. These warning systems include collaboration with local meteorologists for forecasting as well as coordination with multiple agencies and community groups. The goal is to maximize dissemination of actionable information for both immediate health protection and provision of additional services during the period of intense heat. Often the additional services include longer hours at community centers for seniors (called cooling centers during the time they are open during a heat wave) as well as reduced fare on public transportation or the implementation of neighborhood buddy systems. In addition, the NYSDOH distributes statewide a fact sheet entitled "Keep Your Cool During Summer Heat" that provides information on what to do before and during a heat event, how to recognize and act on heat-related illness, and who is most vulnerable. The NYSDOH also has worked with the State Environmental Health Collaborative Climate Workgroup to develop several climate indicators. These include indicators for the vulnerable population (elderly and people living in low-income neighborhoods), cardiovascular disease, hospital readmissions for respiratory diseases due to heat, maximum/minimum temperature, and air pollution change due to heat. One important priority with respect to these efforts is to evaluate their effectiveness in reducing morbidity and mortality.

Home air conditioning is a critical factor for prevention of heat-related illness and death (Bouchama et al., 2007). Air conditioning is especially important for elderly, very young, and health-compromised individuals, all of whom have a lower internal capacity to regulate body temperature (CDC, 2009).

Within New York City, approximately 84 percent of housing units had some form of indoor air conditioning in 2003. Air conditioning rates are not uniform across the city, however. Neighborhoods with higher poverty rates, including Central Harlem, Washington Heights, Fordham, the South Bronx, Greenpoint, Williamsburg, Bedford-Stuyvesant, and others, have lower rates of in-home air conditioning than more affluent parts of the city (**Figure 11.8**). These differences suggest that many residents living in lower-income neighborhoods of the city may be more vulnerable to heat-related illness and mortality.



Note: Percentages are age adjusted. Poverty is categorized by the percent of residents in each neighborhood living below the federal poverty level.
Source: NYC Community Health Survey 2007; Bureau of Epidemiology Services, NYC DOHMH; U.S. Census 2000/NYC Department of City Planning

Figure 11.8 Air conditioning distribution and neighborhood-level poverty in New York City

The presence of an air conditioner does not necessarily equate to its effective use during a heat wave. Also, while fans can be helpful at moderate temperatures, Wolfe (2003) points out that their effectiveness diminishes at very high temperatures and humidity.

As noted in the Chapter 8 ("Energy"), energy costs associated with use of air conditioning are a major concern for lower-income households and particularly for lower-income elderly populations (Tonn and Eisenberg, 2007). Even during periods of extreme heat, low-income elderly residents, particularly those living alone, may be reluctant to use their air conditioners due to concerns about energy costs. While age and social isolation were key factors in predicting mortality in the 1995 Chicago heat wave (Semenza et al., 1996), presence of air conditioning in the home did not necessarily have a mitigating effect. Many of the Chicago heat wave's elderly victims had working air conditioners in their apartments, but the machines were not in use at the time of death (Klinenberg, 2003). Thus, to improve the effectiveness of air conditioning as an adaptive measure, it will be important to develop strategies to ensure energy access for low-income, vulnerable individuals, as well as ensure that functional, high-efficiency air conditioners are widely available and in use. Possible measures include monetary support of low-income populations to ensure the use of air-conditioning and programs for peak load and or voltage reduction (Warren and Riedel, 2004). The costs to implement such measures are not well documented.

In addition to these measures, infrastructure investments, particularly in vulnerable urban neighborhoods, could yield substantial health benefits. Urban greening programs, green roofs, and building codes requiring reflective exterior surfaces are among the options that should be considered.

Air Pollution

Implementation strategies addressing ozone and fine particles are well developed in New York State and are described on the New York State Department of Environmental Conservation website (www.dec.ny.gov/chemical/8403.html; see State Implementation Plan). However, integrating climate forecasts into ongoing planning for air quality is a challenge that must be addressed in collaboration with stakeholders at the New York State Department of Environmental Conservation and the U.S. Environmental Protection Agency.

11.4.2 Larger-scale Adaptations

Comparative health-risk assessments of climate change adaptation (and also mitigation) measures, such as the health effects of the combustion byproducts of biofuels and gases of varying ethanol blends, are important. Data gaps, such as the specifics of relationships between certain climate factors and some health outcomes and projections of climate impacts on multiple types of disease and vulnerable subpopulations, and the specific ongoing need for increased environmental monitoring linked to health outcome reporting, are also key to adaptation. Additionally, stakeholders have voiced the importance of public health communication. Alerts regarding known health risks should be tested and tailored to most effectively convey information and needed action to vulnerable communities. Cross-cutting environment and health initiatives that bridge the divide in legislation between ecosystems and human health should also be developed.

11.4.3 Co-benefits and Opportunities

This chapter has focused primarily on potential negative health impacts of a changing climate in New York State. However, it is possible that climate change may bring some positive impacts on health. For example, warmer winters may reduce the burden of some cold-related health effects (e.g., hypothermia among the homeless, snow-related accidents and injuries) and could encourage greater physical activity during extended periods of mild weather. In addition, policies enacted in New York State to reduce greenhouse gas (GHG) emissions by curtailing fossil fuel burning will reduce emissions of other pollutants, and may deliver health benefits as well. Furthermore, unlike climate benefits, these health co-benefits accrue locally in space and time, enhancing their value in economic analyses (Burtraw et al., 2003; Dessus and O'Connor, 2003; Proost and Van Regemorter, 2003; Wang and Smith, 1999; Bloomberg and Aggarwala, 2008). For 20 years at least, researchers have attempted to quantify co-benefits (Ayres and Walter, 1991; Viscusi, 1994). Most studies have found that the magnitude of the ancillary benefits are large, even relative to the large outlays required by GHG mitigation. Most of the literature to date emphasizes co-benefits that accrue from reductions in air pollution, particularly $PM_{2.5}$ and ozone precursors. However, GHG mitigation policies may improve health in other ways, e.g., via increased physical activity, decreased meat consumption, and reduced traffic accidents. For comprehensive reviews see Bell et al. (2008) and Nemet et al. (2010).

11.5 Equity and Environmental Justice Considerations

Climate change is an evolving problem for human health conditioned by unequal access to resources and differential exposure to unhealthy landscapes. The negative impacts of climate change on health may be particularly consequential for people living in poverty or communities segregated by race.

11.5.1 Vulnerability

There are two important pathways for climate-related health inequities. First, lower-income populations and communities of color may be concentrated in areas exposed to more climate-sensitive health risks. For example, compared to higher-income white populations, low-income segregated African-American and Hispanic communities tend to have greater exposure to allergens and smog, and live in homes that are less able to regulate temperature and humidity (Williams and Collins, 2001; Evans and Kantrowitz, 2002). Second, exposure may impose added burdens on pre-existing vulnerabilities of health, living conditions, and socioeconomic position. For example, low-income communities tend to have inferior public infrastructure, higher risk of underlying health conditions such as cardiovascular disease, and less access to quality, affordable health care (Williams and Collins, 2001; Evans and Kantrowitz, 2002). Other indicators of pre-existing vulnerabilities to climate-related health shocks include lower wages or unemployment, lack of insurance, occupational stresses, and poor nutrition.

Higher temperatures will likely increase the duration and intensity of heat waves and associated heat-related health stresses. Heat-related health stresses are felt disproportionately in inner-city urban areas, where a preponderance of heat-trapping surfaces and a scarcity of heat-reducing infrastructure (trees, parks, water) contribute to the urban "heat island" effect (Rosenzweig et al., 2006). The urban heat island effect has been implicated in past heat wave events (Kunkel et al., 1996). Because of residential segregation patterns, these inner-city neighborhoods also tend disproportionately to house low-income communities of color (Williams and Collins, 2001).

Health risks can be intrinsic or extrinsic. Intrinsic heat-related health risks include age, disability, and underlying medical conditions, such as depression or cardiovascular problems (Stafoggia, 2006; Worfolk, 2000). Some of these medical conditions are more prevalent in low-income communities or within communities of color. Extrinsic risks encompass contextual factors such as behavior, quality of housing, community integration, and access to cooling infrastructure and transportation (Kovats and Hajat, 2007; Epstein and Rogers, 2004; Klinenberg, 2003). Some of these risks are also associated with lower-income status, such as the higher probability of residing in heat-trapping buildings and lacking air conditioning (Klinenberg, 2003). All these risks generally interrelate to create unique, magnified vulnerabilities. For example, elderly persons may be medically sensitive to heat stress (intrinsic), while at the same time may lack coping strategies such as access to community support networks (extrinsic) (Worfolk, 2000; Klinenberg, 2003).

Heat-related morbidity also has its own suite of inequities (Lin et al., 2009). Those most likely to die from heat stress are not necessarily those who would suffer the contextual and indirect harms associated with heat morbidity, such as lost wages and productivity and health care expenses.

Air pollution and respiratory health is another area in which environmental justice concerns arise in the context of climate change. African Americans tend to live in urban centers that are more exposed to primary air pollutants. They also are significantly more likely to be hospitalized and die from asthma (Prakash, 2007). Rising temperatures and increasing emissions create conditions for ozone formation and further inequitably distributed health burdens.

Another climate impact is the probability of increased levels of mold and other allergens. This also contributes to respiratory health problems (Beggs, 2004). Dampness of households, a key variable for mold growth, is associated with socioeconomic status (Gold, 1992).

Environmental justice activists have become increasingly concerned about the contribution of mold to the high rates of hospitalization for asthma among African Americans in cities such as New York (NYS Department of Environmental Conservation, 2008). Tackling these high rates of urban asthma or home allergens through health adaptation programs is one way to reduce health disparities.

Securing access to affordable, good quality, nutritious food for lower-income urban communities of color is a priority area for environmental justice advocates in New York State (NYS Department of Environmental Conservation, 2008). Impacts of climate change on local agriculture could make this goal more challenging to achieve.

11.5.2 Adaptation

Some cities, such as New York, have begun developing adaptation programs because of existing health burdens related to heat stress (Rosenzweig et al., 2006). Other more northerly cities in the state may confront new emergent heat stress. They will need to be proactive to avoid any evolving health inequities related to differential coping capacities within their populations.

Since heat danger is frequently mediated by underlying vulnerabilities, one way to build equity into climate change adaptation mechanisms is a broad-based effort to improve health and reduce social isolation among vulnerable populations, including increasing access to health insurance and social support systems, broadening and diversifying economic activities, and improving education. More targeted adaptations include short-term social mechanisms such as warnings and outreach in conjunction with long-term technical design approaches that reduce ambient heat (Bernard and McGeehin, 2004; Rosenzweig et al., 2006). Ensuring equitable implementation of social prevention requires tailoring messages among and within groups. This means confronting language barriers in outreach and warning systems and targeting at-risk groups, such as elderly, disabled, or otherwise isolated persons. For example, the Phoenix heat wave in 2005 took a particular toll on homeless people (Epstein, 2005). Designing a warning for itinerants with tenuous access to information is a challenge for any outreach system. Through the CDC's Climate-Ready States and Cities Initiative, the New York State Department of Health is conducting an assessment that will examine a range of health outcomes related to extreme weather events, as well as waterborne, food-borne, and vector-borne diseases (www.cdc.gov/climatechange/climate_ready.htm).

One way to build social justice into heat adaptive design is to prioritize energy efficiency and retrofits of public housing, such as installing cooling surfaces and insulation. These synergistic approaches are also discussed in Chapter 8, "Energy." Other strategies that enforce climate-adaptive regulations, such as new building codes, might need to provide support mechanisms, funding incentives, or loans for low-income homeowners and small businesses.

11.6 Conclusions

This ClimAID assessment has identified a set of key existing and future climate risks for public health in New York State. Some health risks arise from increases in the frequency, duration, or intensity of weather events, such as diverse health consequences from more storms and flooding events, and from heat-related mortality and morbidity. Other risks may arise due to gradual shifts in weather patterns, such as changes in vector-borne disease prevalence and distribution, worsening air quality (smog, wildfires, pollen), and related cardiovascular and respiratory health impacts. Similarly, risks to water supply and food production may arise due to increased temperatures and shifting precipitation patterns. While the analyses presented here have been from the perspective of New York State, it is important to note that many of our findings can be generalized to other U.S. locations.

11.6.1 Main Findings on Vulnerability and Opportunities

- Climate will likely change the frequency and severity of existing health problems, while also bringing the possibility of entirely new health risks.
- Impacts of climate change will be particularly significant for people in New York State made more vulnerable because of age, preexisting illness, and/or poverty.
- Illness and death from heat will particularly impact low-income urban residents, the elderly, and those with pre-existing health conditions.

- Climate-related changes in air pollution patterns will be particularly significant for asthmatics and for persons who work, play, or exercise out of doors.

11.6.2 Adaptation Options

Adaptation to climate-related health vulnerabilities in New York State is an evolving process. Aside from heat wave warning and response planning, few climate-specific adaptation strategies yet exist in New York State. Climate impacts and adaptation strategies for the health sector build upon the existing public health system of New York State, which is already engaged to some extent with most of the health domains likely to be relevant to climate change. However, there is the possibility that future climate impacts in the health sector may fall outside of historical experience, presenting new challenges. Of particular concern is that information and capacity for integrating climate change into public health planning remains limited at the local level.

Future adaptations in the health sector should begin by enhancing capacity for climate planning within the existing public health system of New York State, and also by strengthening linkages between health and environmental initiatives.

One key objective is to expand ongoing surveillance of climate-sensitive environmental and health indicators. Surveillance is a central public health function that can inform periodic assessments of emerging risks and anticipated future impacts, and help to guide ongoing adaptation planning.

Another key area of focus should be the development of early warning systems and response plans for a broader range of climate risks, building on the experience with heat systems. Adaptation strategies and messaging should be particularly targeted at, and tailored for, protecting vulnerable populations.

Air quality control efforts will need to increasingly take climate change into account, as well as be integrated with greenhouse gas mitigation strategies, so that maximal health co-benefits are achieved.

A general point worth emphasizing is the importance of integrated health planning across multiple sectors, including environmental quality, parks and recreation, urban planning, food and water supply, and others.

With respect to equity and environmental justice, care is called for in designing both adaptation and mitigation strategies so that disparities can be reduced. Without making this an explicit goal, existing health disparities are likely to be worsened by climate change. People in northern parts of the state may be at particular risk for heat-related health impacts due to lack of adaptation to high temperatures. Mitigation and adaptation actions by New York State should ensure an equitable distribution of costs and benefits.

11.6.3 Knowledge Gaps

Future efforts to address health risks due to climate change will require ongoing, state-based research to inform periodic policy developments. Of particular importance is research to identify cross-sectoral interactions and win-win options for adaptation/mitigation, including extensive health co-benefits assessments.

It is also important to develop and analyze local health impact projections of climate factors and related disease outcomes. Information and capacity building for integrating climate change into public health planning at all levels of government is needed.

Examining the effectiveness of heat warning systems and related adaptive strategies, and translating these strategies to urban areas across the state, should be high priorities.

Enhanced environmental monitoring of climate-related factors linked to health outcome reporting, particularly of airborne allergens and infection vectors, is crucial for improving the knowledge foundation on which decisions are based.

Case Study A. Heat-related Mortality among People Age 65 and Older

As a result of climate change, New York State will experience increased temperatures that could have significant consequences for health, particularly for the most vulnerable members of the population: the elderly, those with low incomes, those with limited mobility and social contact, those with pre-existing health conditions and belonging to nonwhite racial/ethnic groups, and those lacking access to public facilities and transportation or otherwise lacking air conditioning. Urban areas are especially vulnerable because of the high concentrations of susceptible populations and the influence of the urban heat island effect. Thus, preparing for and preventing heat-related health problems is likely to be of growing importance in urban areas.

Projecting Temperature-related Mortality Impacts in New York City under a Changing Climate

Climate change has led to increasing temperatures in urban areas in recent decades, and these changes are likely to accelerate in the coming century. These changes may result in more heat-related mortality but also might alter winter mortality, and the net impact remains uncertain. Our objective was to explore a methodology for projecting future temperature-related mortality impacts over the full year in New York County across a range of climate change models and scenarios. The ClimAID climate team provided temperature projections for the 2020s, 2050s and 2080s over New York County, obtained from five different global climate models (GFDL, GISS, MIROC, CCSM and UKMO) that were run with the Intergovernmental Panel on Climate Change (IPCC) A2 and B1 greenhouse gas emissions scenarios (see Chapter 1, "Climate Risks," for details). Monthly differences between modeled future temperatures and those modeled for the climatological baseline period of 1970–1999 were used to adjust observed daily temperatures for 1970–1999 in Central Park, NY to the future time periods.

The association between maximum temperature and daily mortality in 1982–1999 was modeled using log-linear Poission regression analysis. Seasonal cycles were controlled using a natural spline function with 7 degrees of freedom per year. Day-of-week effects were also controlled. Temperature effects were fit using a natural spline with 2 degrees of freedom, yielding a U-shaped curvilinear relationship (**Figure 11.9**). Percentage changes in mortality in both winter and summer were calculated relative to the minimum point on **Figure 11.9**. This analytical approach is similar to those used extensively in the literature (for example, Curriero, Heiner, et al., 2002; Curriero, 2003; O'Neill, Zanobetti, et al., 2003; Anderson and Bell, 2009). We analyzed mortality in relation to maximum daily temperature observed on the same day as death (i.e., lag zero) for both heat and cold effects. This contrasts with the approach used by Anderson and Bell (2009) in which cold effects were modeled as a 25-day moving average. We avoided this approach because it might lead to confounding by winter season effects, that is, a tendency to mis-attribute seasonal effects to the cold slope. The heat- and cold-related deaths in the 1970s, 2020s, 2050s, and 2080s were estimated by integrating the results from the climate models and the empirical exposure-response relationship, with results shown in **Tables 11.1** and **11.2**, and **Figure 11.10**.

During the baseline period, 1970–1999, we estimated there were on average 604 mean annual temperature-related deaths. Under the A2 scenario, mean annual temperature-related deaths increased to 686 in the 2020s, 782 in the 2050s, and 920 in the 2080s. In the B1 scenario, the mean annual temperature-related deaths were 681 in 2020s, 741 in the 2050s, and 779 in the 2080s. Differences across models and scenarios were minimal early in the century but increased by mid-century (**Figure 11.10**). Warm season impacts on mortality expanded in both number and in annual extent (i.e., earlier in spring and later in fall) as the century progressed (**Table 11.2**). Additional sensitivity analyses using alternative lags of temperature and different reference temperatures are under way. However, these preliminary results suggest that, over a range of models and scenarios of future greenhouse gas

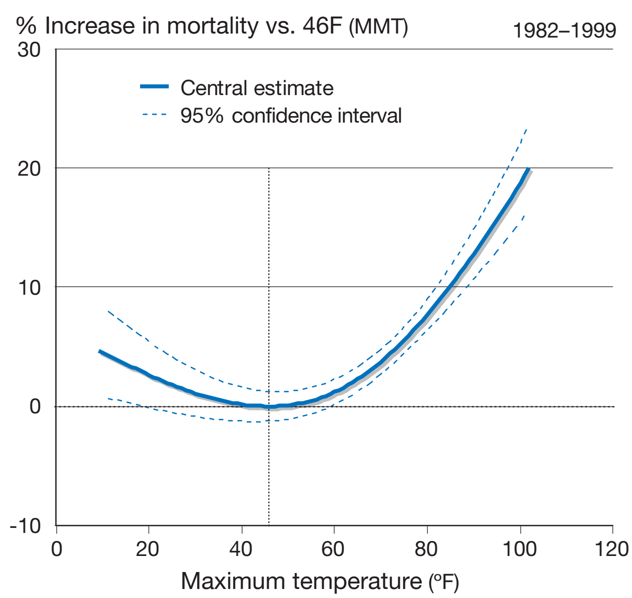


Figure 11.9 Predicted mortality vs. maximum temperature, based on analysis of daily observations from 1982 through 1999

emissions, increases in heat-related mortality could outweigh reductions in cold-related mortality. Further, while the two emissions scenarios produce similar mortality estimates through mid-century, the lower-emission B1 scenario could result in substantially smaller annual mortality impacts by the 2080s.

Economic Impacts of Mortality Due to Heat Waves

As noted above, climate projections can be used in assessing the impact of heat waves on the public health sector and society as well as the effectiveness of potential remedies. Measures to prevent increased mortality during extreme weather events may be

Climate Model	Scenario		Net Temperature Effect		Heat Effect			Cold Effect		
		T_{maxave}(ºF)[a]	Deaths[b]	Percent Change[c]	Days Above MMT	Deaths[b]	Percent Change[c]	Days Below MMT	Deaths[b]	Percent Change[c]
Baseline[d]		62.7	604		287	586		78	18	
GFDL	2020s A2	64.4	676	11.92%	294	660	12.63%	72	16	-11.11%
	2020s B1	64.6	674	11.59%	297	659	12.46%	68	15	-16.67%
	2050s A2	66.6	763	26.32%	304	751	28.16%	61	12	-33.33%
	2050s B1	66.0	748	23.84%	299	735	25.43%	66	14	-22.22%
	2080s A2	69.5	902	49.34%	320	894	52.56%	46	8	-55.56%
	2080s B1	66.8	778	28.81%	304	765	30.55%	61	13	-27.78%
GISS	2020s A2	64.4	670	10.93%	295	655	11.77%	70	15	-16.67%
	2020s B1	64.9	679	12.42%	300	666	13.65%	65	13	-27.78%
	2050s A2	66.1	726	20.20%	306	716	22.18%	59	10	-44.44%
	2050s B1	65.2	694	14.90%	299	681	16.21%	65	13	-27.78%
	2080s A2	68.5	818	35.43%	320	812	38.57%	46	7	-61.11%
	2080s B1	65.5	715	18.38%	299	702	19.80%	64	12	-33.33%
MIROC	2020s A2	65.2	697	15.40%	300	685	16.89%	65	13	-27.78%
	2020s B1	65.3	696	15.23%	301	684	16.72%	64	12	-33.33%
	2050s A2	67.8	798	32.12%	314	790	34.81%	52	9	-50.00%
	2050s B1	67.0	765	26.66%	310	755	28.84%	55	10	-44.44%
	2080s A2	71.5	957	58.44%	333	953	62.63%	32	4	-77.78%
	2080s B1	68.3	819	35.60%	317	811	38.40%	47	7	-61.11%
CCSM	2020s A2	65.3	695	15.07%	300	683	16.55%	65	12	-33.33%
	2020s B1	65.6	700	15.89%	302	689	17.58%	62	11	-38.89%
	2050s A2	68.0	807	33.61%	314	798	36.18%	50	9	-50.00%
	2050s B1	66.6	728	20.53%	313	720	22.87%	52	9	-50.00%
	2080s A2	70.6	927	53.48%	326	922	57.34%	39	5	-72.22%
	2080s B1	66.4	735	21.69%	306	725	23.72%	59	10	-44.44%
UKMO	2020s A2	64.6	685	13.41%	294	673	14.85%	71	16	-11.11%
	2020s B1	64.0	658	8.94%	292	643	9.73%	72	15	-16.67%
	2050s A2	67.4	819	35.60%	306	805	37.37%	59	10	-44.44%
	2050s B1	66.5	768	27.15%	302	756	29.01%	63	12	-33.33%
	2080s A2	71.3	997	65.07%	323	991	69.11%	42	6	-66.67%
	2080s B1	68.6	850	40.73%	317	842	43.69%	48	8	-55.56%
Average Across Models	2020s A2	64.4	686	13.6%	297	671	14.5%	68	14	-22.2%
	2020s B1	64.6	681	12.7%	299	668	14.0%	66	13	-27.8%
	2050s A2	66.6	782	29.5%	309	772	31.7%	56	10	-44.4%
	2050s B1	66.0	741	22.7%	305	729	24.4%	60	11	-38.9%
	2080s A2	69.5	920	52.3%	324	914	56.0%	41	6	-66.7%
	2080s B1	66.8	779	29.0%	309	769	31.2%	56	10	-44.4%

[a] Mean daily maximum temperature (MMT) in ºF for typical year, from observations for baseline period and from climate models simulations for 2020s, 2050s, 2080s.
[b] Central effect estimate for the net temperature, cold- and heat- related additional deaths in a typical year.
[c] Percentage change in central estimate of additional deaths in a typical year, relative to the baseline.
[d] Baseline refers to 1970-1999 reference period.

Table 11.1 Summary of projected annual mean daily maximum temperature and associated additional deaths in the 1970s versus the 2020s, 2050s, and the 2080s, in the A2 and B1 scenarios for 5 of the 16 global climate models used in ClimAID

Month	Base	A2			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
1	9	8	18	19	8	19	19
2	7	7	16	19	7	17	17
3	10	11	35	52	12	31	38
4	27	35	105	130	34	103	99
5	63	73	206	251	73	198	210
6	99	108	305	354	111	291	305
7	135	151	418	476	148	401	420
8	124	139	394	454	137	369	390
9	79	90	260	297	88	241	257
10	34	42	130	160	41	121	125
11	12	16	48	66	16	45	50
12	6	6	19	24	7	18	19

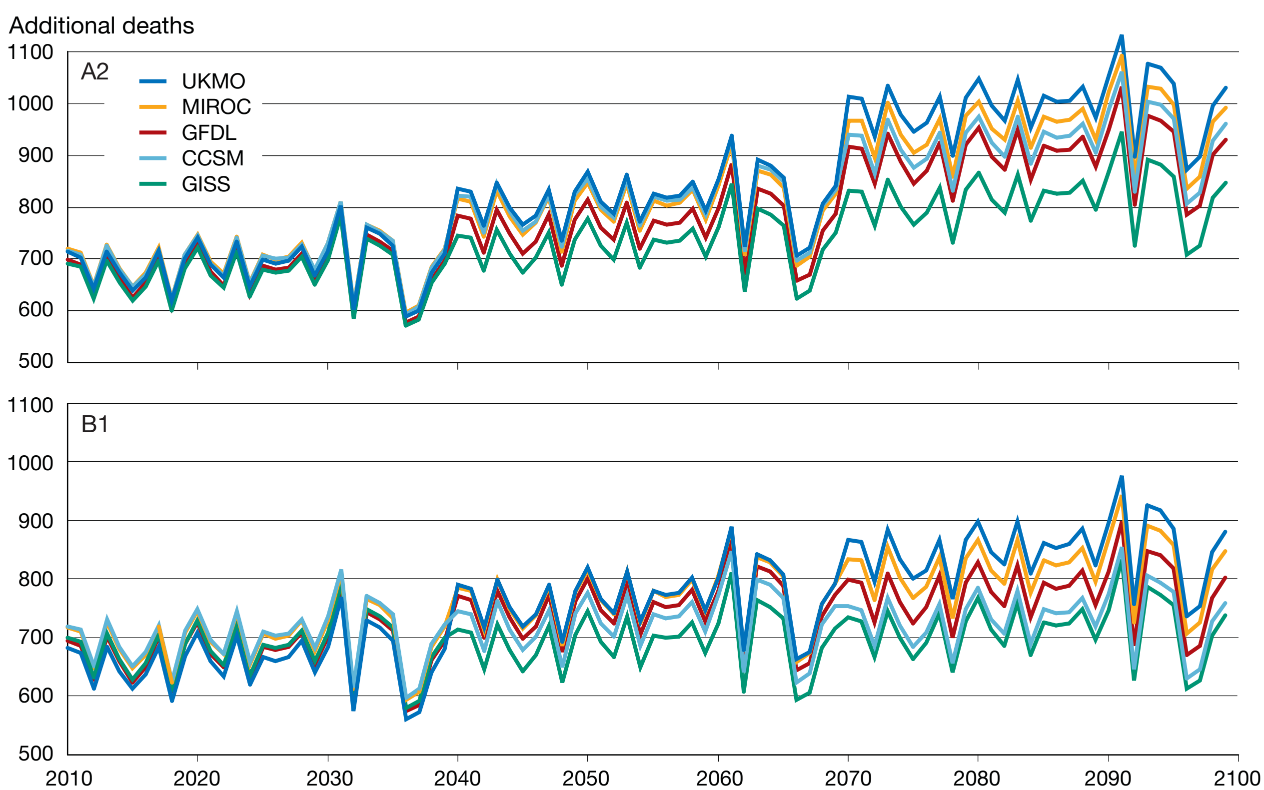
These are 5 of the 16 GCMs used for ClimAID climate projections.

Table 11.2 Average (across five global climate models) projected monthly additional deaths in the 1970s versus the 2020s, 2050s, and 2080s, A2 and B1 scenarios

evaluated in terms of economic net effects. Most public policy decisions requiring economic assessments include estimating the costs of the proposed actions against those ensuing from inaction. The calculus of economic losses from increased mortality includes assigning monetary values to human life as well as estimating costs associated with services rendered before death (e.g., emergency/ ambulance services and/or hospital stay) and/or averting behavior (e.g., purchasing air conditioning units).

Some economics assessments measure mortality as the change in the probability of dying for a specific population due to a change in health status. This does not represent the "crude" mortality rate of the population, measured as the ratio of the total number of deaths divided by the total number of individuals in the population. Instead, some economics methods assume that individuals are able to rank other traded goods against the "value of a statistical life" (VSL) or the "value of a statistical death avoided" (Krupnick, 1996). In this perspective, death and illness are treated as probability rates and individuals as willing to pay to reduce marginal changes in the probability of death or incidence of illness. Thus, people are assumed to be making informed choices about the rate of substitution between small changes in the probability of death or illness, and other traded goods.

Based on such assumptions, various studies have developed coefficients to estimate the value of a statistical life in order to evaluate economic losses ensuing from premature mortality. Two methods may be



These are 5 of the 16 GCMs used for ClimAID climate projections.

Figure 11.10 Annual net additional deaths in the 21st century for five global climate models for A2 (top) and B1 (bottom) emissions scenarios used to identify the VSL in relation to reduced mortality risks. The first is based on surveys that gather information on people's willingness to pay (WTP) to decrease mortality risks. The second one is based on the "revealed preferences" method and applies a "willingness to accept compensation" (WTA) approach to estimate VSLs by using hedonic wages or differential wage rates (Ebi et al., 2004). Hedonic wages are statistically based estimates of the wage rates of different types of jobs based on the characteristics of the jobs. Jobs that are more unpleasant or pose health and safety risks for workers typically pay higher wages than other types of jobs, and hedonic models can be used to estimate the value of these wage differences. In general, the results of both methodologies have been found to be similar (Ebi et al., 2004), with heterogeneity in age and income levels playing a role in explaining variations.

Most studies applying the above methodologies report VSL in dollars per life saved. For example, when evaluating the benefits of policies to reduce pollution, the U.S. Environmental Protection Agency reported VSLs ranging from $2.3M to 11.8M (Smith et al., 2001). Updated estimates provide a central VSL of $7.4 M (in 2006 dollars) (U.S. EPA, 2000, 2004, and 2010). Other recent studies have estimated the value of statistical life averaging $7 million (Viscusi & Hersh, 2008). Another study, which assessed VSL values for Ontario based on wage rates, placed the value of a statistical life as ranging from 0.92M to 4.54M (Krupnick et al., 2000).

Results from surveys assessing WTP to reduce mortality risks are expected, in theory, to reflect the individual characteristics of respondents. These results may be subject to a certain degree of heterogeneity, in particular because of differences in age and income levels of the population sample surveyed. With respect to age, VSLs are seen to increase up to age 50 and then decrease, with older people having the lowest values. For example, a WTP survey of Canadians found that individuals in a 70 to 75 year-old cohort were less willing to pay to reduce mortality risks than cohorts of younger adults (Krupnick et al., 2000). Nevertheless, this study found that the VSL did not decline (per age group) for people whose health is compromised, regardless of the health problem. Another VSL study explored the simultaneous effect that income levels and age have on WTP surveys, within the context of the hedonic wage model (Evans and Schaur, 2010). The authors found that the impact of age on the wage–risk tradeoff varies across the wage distribution. Results are shown in **Table 11.3**.

An alternative approach measures the VSL based on the years of potential life lost (YPLL). This approach has been advanced to consider younger age groups that may lack income streams by assigning heavier weights to premature mortality at younger ages (CDC, 1986). The YPLL approach has also been used to account for differential health status by ethnic background (CDC, 1989).

The economic burden to the health care system must also be taken into account when estimating losses from increased mortality due to heat waves. The elderly, children, and persons with certain medical conditions are at greatest risk for heat-related illness and death. Of particular concern are those individuals affected by cardiovascular disease (CVD), which accounts for more deaths in the United States than any other major cause, with roughly two-thirds related to coronary heart disease (CHD) and stroke (Yazdanyar, 2009). In 2009, costs associated with treating CVD and stroke in the United States were expected to exceed $475 billion, with direct costs, such as services at hospitals or nursing home facilities, professional fees, and medicines, estimated to reach over $313 billion. While not all such

Point in the Real Wage Distribution	Real Hourly Wage	Marginal Impact of Risk	VSL (million $)	Marginal Impact of Risk	VSL (million $)	Marginal Impact of Risk	VSL (million $)
		50-year-old		55-year-old		60-year-old	
10%	6.49	0.07	9.08	0.025	3.24	<0	<0
25%	8.85	0.089	15.75	0.049	8.67	0.009	1.59
50%	13.07	0.251	65.59	0.231	60.36	0.211	55.14
75%	19.49	0.156	60.81	0.141	54.97	0.126	49.12
Mean	15.97	0.046	14.69	0.016	5.11	<0	<0

The VSL estimates are given in 1998 dollars, and have been calculated as: Marginal Impact of Risk*Real Wage*x*y*z, where x=40, y=50, and z=10,000
Source: Evans & Schaur, 2010

Table 11.3 Estimated marginal impacts of risk on the real wage and associated value of statistical life estimates by age and real wage costs are related to extreme heat events, CVD prevalence is likely to be exacerbated during such periods, thus putting additional strain on the public health system and its efforts to reduce CVD incidence. Furthermore, costs are projected to increase in future decades, as the size of the elderly population in the United States is expected to grow (American Heart Association, 2008; Yazdanyar, 2009).

Research conducted in Canada shows that costs associated with elevated mortality due to heat waves and air pollution are of concern. 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, with the value per premature death (based on estimates of lost earning power) estimated as $2.5 million. An additional $7 million a year is being spent by these cities on health care (Cheng et al., 2005).

Mortality cost associated with heat in New York City could be estimated by multiplying the EPA VSL estimate of $7.4 million by the mortality cases identified in the analysis presented above. Such calculation may be adjusted by taking into account findings by Krupnick et al. (2000), if mortality cases for the cohort group of 65 years of age and older are known.

Mortality costs, while significant in terms of lives lost, are only part of the economic costs to society. Table 9.6 in Annex III of the ClimAID report ("An Economic Analysis of Climate Change Impacts and Adaptations in New York State") summarizes the costs associated with major heat waves from 1980 to 2000, which range from $1.3 billion to $48.4 billion, depending on the severity of the event. As this table shows, each major event can accrue considerable costs. It also shows that mortality rates in the central and eastern U.S. are higher (~5,000–10,000 deaths per heat event) than for states that may be better prepared to sustain heat events.

Adaptation Measures

Several cities across the United States and Canada have instituted emergency response plans to address increased mortality rates during extreme heat events. Examples of these response plans include the "Philadelphia Hot Weather-Health Watch/Warning System" (PWWS) set in operation in Philadelphia after the heat wave of 1995 (Ebi et al., 2004) as well as Toronto's "Heat-Health Alert System" (HHAS) (http://www.toronto.ca/health/heatalerts/alertsystem.htm). Given that extreme heat periods are likely to become more prevalent with climate change, other cities are expected to implement similar plans.

The emergency response plans include early warning systems to alert the population about extreme weather events and help the public health sector forecast resource requirements as well as community outreach and other services. For example, Toronto's HHAS includes a team of 900 individuals and community agencies that conduct outreach to vulnerable populations, including delivering water to them. Many cities extend hours of operation at various air-conditioned facilities, or set up cooling centers and arrange transportation to these locations. Air conditioning plays an important role in preventing heat-related mortality. Working air conditioners and participation in group activities have been identified as important preventive measures (CDC, 2003). The evidence from the two Chicago heat waves suggests that mortality risks were larger for individuals with cardiac disease or psychiatric ailments and those living alone. Therefore, outreach to vulnerable populations is seen as an important protective factor (Klinenberg, 2002).

Benefits associated with implementing such systems are seen to outweigh their costs, as documented by a study of the PWWS in Philadelphia (Ebi et al., 2004). While many of the measures taken when issuing a heat warning are reported to be included as part of the city employees' jobs, others require direct costs, such as wages for deploying Heatline (a hotline to provide information and counseling to the public on how to avoid heat stress) and additional Emergency Medical Service (EMS) crews. The study reports that additional wages are calculated at $10,000 per day over a period of three years. Given that during that period the City of Philadelphia issued 21 alerts, costs for the system were estimated at $210,000. The value of 117 lives saved over the same time period was estimated to be $468 million.

Other adaptive measures include monetary support of low-income populations to ensure the use of air conditioning and recommendations for temporary rolling brownouts or blackouts to prevent prolonged blackouts, which have been seen to increase mortality rates during a heat wave (Warren and Riedel, 2004). The costs to implement such measures are not well documented.

Case Study B. Ozone and Health in New York City Metropolitan Area

Knowlton and colleagues examined scenarios for climate impacts on ozone-related and temperature-related mortality in the New York City metropolitan area (Knowlton et al., 2004). Here we summarize the key methods and findings from that work.

The New York Climate and Health Project (NYCHP) was designed to project the relative health impacts of local climate-related changes in temperatures and ground-level ozone concentrations. They compared acute summertime non-accidental mortality during the 1990s to several future decades (2020s, 2050s, and 2080s). They used a four-part methodology to assess region-specific mortality impacts. First, they sought to develop mortality exposure-response functions for temperature and ozone effects on summer mortality, using historical (1990–1999) death, weather, and air quality data for the study area. Next, they developed an integrated modeling system that included modules for global climate, regional climate, and regional air quality. Third, the retrospective epidemiological analysis was combined with the projective integrated climate-air quality model system through application of a health risk assessment, and current versus future mortality was compared to assess potential mortality risks in the metro area in the 21st century. Lastly, a sensitivity analysis examined alternative greenhouse gas (GHG) growth scenarios in order to assess how reduced GHG emissions might reduce potential adverse health impacts of climate change.

Mortality data were obtained from the U.S. National Center for Health Statistics (NCHS) for 1990–1999. Daily death counts within each of the 31 counties for all internal causes (International Classification of Diseases ICD-9 codes 0–799.9 for 1990– 1998 and ICD-10 codes A00–R99 for 1999) were pooled, excluding accidental causes and those among nonresidents, to obtain a set of daily summer regional death count totals.

Air quality data were obtained from the U.S. EPA's Aerometric Information Retrieval System (AIRS) for ozone monitoring stations within the study area. Of 39 reporting stations in the study area with ozone data on any of the 920 summer days from 1990–99 (10 summers x 92 days/summer), those with fewer than 80 percent non-missing days were removed from further analyses. For the 16 remaining stations, there were 13,743 monitor-days with data (93.4 percent) and 977 monitor-days (6.6 percent) for which data was interpolated. None of the 920 study days had region-wide average ozone concentrations based wholly on imputed data.

Daily mean temperature (T_{ave}) and dewpoint temperature (both in °F) data were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) data inventory. Stations within the study area with at least 80 percent non-missing T_{ave} data included 16 meteorological stations. Only six airport stations had daily dewpoint data for the years in question, and humidity was not included in the statistical final model.

A statistical model was developed using Poisson regression with log daily death counts as the outcome variable. From b and standard error (SE) estimates the incremental changes in the relative risk of mortality were calculated for T_{ave} and the mean of lag 0 and 1 for maximum 1-hr average ozone.

To estimate future climate, the GISS coupled global ocean/atmosphere model was driven by two different IPCC greenhouse gas scenarios, A2 and B2, with results downscaled to a 36-kilometer grid resolution using the MM5 regional climate model (Lynn et al., 2010). To simulate ozone air quality, the Community Mesoscale Air Quality (CMAQ) model was run at 36-kilometer and took its meteorological conditions from the GISS-MM5 simulations. The simulation periods were June–August, 1993–1997; June–August, 2023–2027; June–August, 2053–2057; and June–August, 2083-2087. Full details are found in Hogrefe et al. (2004a; 2004b). MM5 model simulated temperatures and CMAQ simulated ozone concentrations across the model domain in summers for these four future decades. Gridded temperatures and ozone concentrations were interpolated to county centroid latitude/longitude coordinates using inverse distance weighting from the three nearest station data to individual county centroids, for use in the county-level mortality risk assessments.

The risk assessment evaluated the daily summer ozone-related mortality increase by application of b coefficient estimates from the epidemiological analysis in the formula:

Equation 1: Additional O_3-related mortality = (Population/100,000)* (Daily mortality rate) * [exp((maxO$_3$ (h)$_{ave(48)}$) * β))-1]

To isolate climate effects in estimates of future mortality risks, they held population constant at the Census 2000 county totals. They also held anthropogenic ozone precursor emissions constant at the 1996 inventory levels and assumed mortality rates would remain constant at county-specific mean 1990s reference rates. To project changes in summer ozone-related mortality relative to the 1990s, the risk assessment was applied to 1-hour maximum ozone concentrations in five 1990s summers from station observations versus from five mid-decade summers from CMAQ simulations (i.e., 1993–1997 versus 2023–2027, etc.) at 36-kilometer horizontal resolution. The mean concentrations from lag days 0 and 1 (i.e., the same and previous days) were calculated so that the corresponding transfer function estimates from the Poisson GAM (generalized additive model) model could be applied in the ozone-mortality regression analysis. The statistical model was run for each decade, using SAS version 9.0 (SAS Institute, 2002) to apply the linear-quadratic-cubic heat and the linear ozone effects.

Mortality for a typical summer in each decade was evaluated and compared to that in a typical 1990s summer. The absolute and relative (percentage) changes in climate-related mortality in the 2050s under the A2 and B2 scenarios are shown in **Table 11.4** for both ozone and temperature. While larger O_3-related mortality was projected for the New York metropolitan region under the B2 scenario assumptions, different patterns across the eastern U.S. exist; domain-wide, O_3 is projected to increase more under the 2050s A2 scenario than under B2.

	1990s	2050s B2 (lower CO_2 emissions)	2050s A2 (higher CO_2 emissions)
Projected summer heat-related mortality	1116	2013 80% increase relative to 1990s	2347 110% increase relative to 1990s
Projected summer O_3-related mortality	1059	1139 7.6% increase relative to 1990s	1108 4.6% increase relative to 1990s

Table 11.4 Projected heat-related and ozone-related mortality impacts during summer in the 2050s, comparing A2 vs. B2 greenhouse gas emission scenarios

Case Study C. Extreme Storm and Precipitation Events

Climate projections of extreme precipitation events, such as hurricanes, indicate increased health risks associated with flooding, storm surges, and severe winter storms. Public health impacts range from direct effects of injury and drowning to longer-term effects on mental health, health service delivery, municipal water infrastructure, respiratory and gastrointestinal tracts, and exposure to toxins. Sea level rise could exacerbate health vulnerabilities of coastal populations, and developed coastal areas may face increased risks of evacuation-related health impacts and stress, including household disruption.

Projected increases in duration and amount of rain as well as extreme wind and snow associated with nor'easter storms present risks of flooding and damage to property and critical infrastructure. The New York City Panel on Climate Change (NPCC) projects that annual precipitation is likely to increase by 0 to 5 percent by the 2020s, 0 to 10 percent by the 2050s and by 5 to 10 percent by the 2080s (NPCC, 2010). Specifically, periods of intense precipitation (defined as either volume per hour or consecutive days of rainfall) are likely to increase into the next century (NPCC, 2010).

Injury and Mortality

Hundreds of injuries and deaths are caused every year by severe storms and precipitation across the United States (Greenough et al., 2001). Flash floods, resulting from intense rain over a short period of time, are of specific concern because they leave little time for warning or evacuation. Drowning accounts for a large majority of deaths during flooding events (Greenough et al., 2001). A review of National Weather Service reports identified inadequate warning systems to be an important mortality risk factor in flooding emergencies (French et al., 1983). Urban areas are particularly vulnerable to flash flooding due to the inability of extensive concrete surfaces to absorb precipitation (Greenough et al., 2001). Additionally, increased volume and duration of snowfall and ice accumulation pose theoretical increased risk of injury, including head trauma and lacerations from falling, vehicular accidents, and hypothermia; however, no studies were found that have quantified these effects.

Mental Health

While mental health effects are difficult to quantify, they have been among the most common and long-lasting post-disaster impacts. Studies following hurricane events over the past 30 years have shown both high prevalence (Norris et al., 1999) and long duration (Logue et al., 1979) of post-traumatic stress disorder among survivors. Depression, substance abuse, and anxiety have also been documented following hurricane and flood disasters (Fried, 2005; Verger, 2003; Weisler, 2006). These mental health conditions are of concern not only for their toll on individuals and families, but also because they can impair recovery efforts and limit resiliency for future events.

Indirect Effects

Indirect health effects are those linked to disturbances in ecological or infrastructure systems upon which we depend, such as impacts to water supply quality and quantity. Effects can be lessened through effective preparedness and mitigation measures. Heavy rainfall events can contaminate water systems by altering runoff patterns and can trigger waterborne disease outbreaks (Auld and Klaassen, 2004). Intense rain events can lead to illness associated with giardia, cryptosporidium, and *E-coli*, among other food-borne and water-borne pathogens. More than half of water-borne disease outbreaks occur after severe precipitation events. An analysis of nearly 50 years of continental U.S. weather records found that 51 percent of waterborne disease outbreaks followed precipitation events that were in the top 10 percent of heaviest rainfall events for the area, and that 68 percent followed events in the top 20 percent (Curriero et al., 2001). Drinking water originating from both surface and groundwater sources becomes vulnerable (Curriero et al., 2001). Such severe precipitation events are likely to be experienced in New York State (see Chapter 1, "Climate Risks") and should be incorporated into risk mitigation planning. In response to these known vulnerabilities and projected challenges of changing precipitation regimes, the New York City Department of Environmental Protection has developed a comprehensive watershed protection plan and water quality monitoring infrastructure (NYCDEP, 2008).

While the hazard of cross contamination of drinking water and sewage infrastructure is not considered a threat to most urban infrastructure, storm system overflow due to heavy precipitation can result in sewage outflow through street-level drains and building basements. System overflows can create opportunities for bacterial infection through exposure to sewage through standing water and green spaces. Chemical toxins from industrial or contaminated sites, including heavy metals and asbestos, can be mobilized during flood and precipitation events (Euripidou, 2004). Residential and recreation areas near brownfields or industrial sites are potential sites for chemical exposures.

Flooding of buildings and standing water have been associated with respiratory problems upon reoccupation of homes that have potentially long-term effects for both residents and remediation workers (Solomon, 2006). As floodwaters recede, molds and fungi can proliferate and release spores that can cause respiratory irritation and allergic reactions when inhaled. Elevated indoor mold levels associated with flooding of buildings and standing water are risk factors for coughing, wheezing, and childhood asthma (Jaakkola et al., 2005; Bornehag et al., 2001). Outdoor molds in high concentrations have also been registered following flood events and are associated with allergies and asthma, with particular risks to children (Solomon, 2006). Safe and timely mold remediation is an important concern for weather-response planning. The New York City Department of Environmental Protection and the Office of Emergency Management already have such plans in place. (See Chapter 5, "Coastal Zones," for a description of permanent and repeated inundation risks related to sea level rise.)

Additionally, extreme events that disable critical infrastructure or interrupt the delivery of health services—even for a brief amount of time—could represent critical risks for certain vulnerable populations. Chronic health conditions, such as asthma, diabetes, and kidney disease, require frequent and timely medical attention, the absence of which could exacerbate health conditions and increase demand for emergency hospital services. Household preparedness and emergency stockpile and distribution networks for critical medications could prove an important component of adaptation planning.

Case Study D. West Nile Virus

In the U.S., more than 25,000 cases of human disease caused by West Nile virus have been reported since its introduction to North America in 1999, and hundreds of thousands of birds have been killed by the infection. The disease-causing pathogen replicates within some species of wild birds and is transmitted among birds and other hosts (including humans) via the bite of infected mosquitoes. Human risk of exposure to West Nile virus is correlated with both the abundance and infection prevalence of mosquitoes carrying the pathogen (Allan et al., 2009). Although the number of infected mosquitoes depends on the infection rate of the hosts upon which they feed, the number of mosquitoes is likely to increase with rising temperatures and a wetter climate. In New York State, the species of mosquitoes that are most likely to carry West Nile virus are those that breed in natural or artificial containers, such as ponds and discarded tires, respectively, including *Culex pipiens*, *Culvex restuans*, and *Aedes albopictus*. While West Nile virus infections in humans and birds have only been reported in a limited part of the state, the prevalence of West Nile virus in mosquitoes is more widespread throughout the state (**Figures 11.11a** and **11.11b**).

In the eastern United States, human incidence of disease caused by West Nile virus at the county level is correlated with above-average total precipitation in the previous year (Landesman et al., 2007). Higher total precipitation likely results in more immature mosquitoes surviving over the winter, which leads to a greater abundance of adults the following year. In Erie County, New York, a higher number of adult mosquitoes in the summer is correlated with cooling degree days base 63 and 65 (degree days above 63 to 65°F) seven to eight weeks earlier, with the product of cooling degree days base 63 and precipitation four weeks earlier, and with rates of evapotranspiration (the loss of water from soil evaporation and plant transpiration) five weeks earlier, although these relationships are complex and nonlinear (Trawinski and MacKay, 2008).

At the national level, higher incident rates of West Nile virus disease are associated with increased weekly maximum temperature, increased weekly average temperature, increased average weekly dew point temperature (the temperature at which water vapor condenses into water), and the occurrence of at least one day of heavy rainfall within a week (Soverow et al., 2009).

Climate change is expected to increase precipitation and summer temperatures in New York. Therefore, in general, risk of human exposure to West Nile virus is expected to increase in the state as the climate becomes warmer and wetter. Quantitative predictions about changes in risk that are specific to regions within the state will require more extensive site-specific data on the relationships between climate variables, the distribution of mosquitoes, the density of their populations and their behavior, and virus replication rates.

Figure 11.11a Numbers of cases of West Nile illness in humans, New York State, 2008

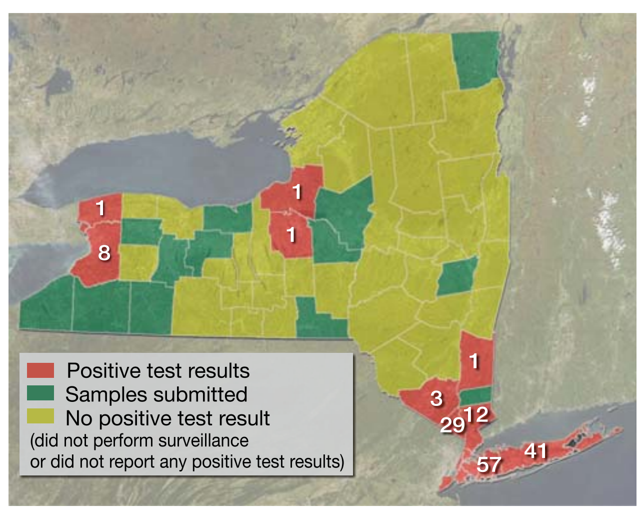


Figure 11.11b Numbers of mosquito samples testing positive for West Nile virus, New York State, 2008

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Appendix A. Stakeholder Interactions

A diverse network of stakeholders and partner organizations has been developed over the course of several assessments carried out by the ClimAID Public Health sector team since the late 1990s. The stakeholders include city, state, and federal governmental agencies in the areas of environment, health, planning, and emergency management; non-governmental environmental organizations; academic institutions with research interests in public health and climate change; environmental justice organizations; clinical health sector organizations; and community-based organizations targeting the elderly, youth, and low-income populations. Stakeholder engagement, involving approximately 100 stakeholders, included direct interviews, informal discussions, attendance at specially convened task forces, and an online survey administered to county health officials across the state.

Stakeholder Concerns

Our first approach involved phone interviews with a subset of key stakeholders at the following agencies and organizations: New York City Department of Health, New York City Mayor's Office of Long Term Planning and Sustainability, a national environmental non-governmental organization, and the New York State Department of Environmental Conservation. The climate-related health issues identified in these interviews included concerns about heat events; vector-borne illnesses such as West Nile virus (the first case in the United States occurred in New York City); other emerging infections; extreme storms (causing health risks from contaminated watersheds as a result of coastal storms, which cause flooding hazards, injury risks, and surface water quality issues that necessitate beach closures); waterborne illness; air pollution such as ground-level ozone, particulate matter and airborne allergens; and population displacement. Additional concerns expressed included the need for a full assessment of potential health effects of adaptation measures such as air pollutants from biofuels.

The stakeholders also identified needs for planning and adaptation. They reported that specific geographic variation of health impacts as well as specific population vulnerability information would be helpful in tailoring community-level adaptation projects and media messaging. Additionally, they reported that health cost-benefit analyses could assist policymakers in choosing between various planning options. Overall, there was strong consensus regarding the need for ongoing environmental and environmental health monitoring and for more data on the effectiveness of different adaptation measures. Evaluation research on the effectiveness of different adaptation measures was also identified as useful, e.g., heat-response plans, including cooling centers, public advisories about heat and the need for hydration, and buddy systems.

Some stakeholders raised concerns that transcended sectors. They questioned if the energy grid can provide continuous output during an extended heat wave and whether there is potential for failure of the power grid. Additional concerns involved energy and air quality feedbacks that could have potential health effects (i.e., power plants may burn dirtier fuels during heat waves to accommodate power demands). Also, as the risk of flooding increases, potential mold problems could increase. Lastly, concerns were raised over the impact of climate change effects on New York City's water supply. This relates to a more general area of interest voiced by our stakeholders: the increased risk of waterborne illness following high precipitation events. The importance of identifying vulnerable communities—by virtue of age, socioeconomic status, or underlying medical conditions, for example—and particular areas statewide that are more likely to be affected was emphasized.

Similar issues were raised in our informal group meetings with physicians, students, and community residents. There is a considerable amount of interest and concern about climate change and its potential health impacts. However, the knowledge base remains limited.

Emerging Adaptations

New York City has been proactive in developing climate-risk information processes for several health-relevant climate risks (NPCC, 2010). Climate-protection levels developed by an advisory group for 2050 and 2080, which include the projected number and severity of heat waves, sea level rise, and extreme rain events, are being used to guide infrastructure policy and codes. Infrastructure is broadly defined to include water, energy, and bridges. Additionally, there are efforts to increase the proportion of the vulnerable population with access to home air conditioning.

Additional adaptation measures that are within the purview of the New York City health and housing codes include beach closing after extreme rain events until water quality meets safety standards and wiring in buildings for energy efficiency and safety.

On the state level, there is a "Climate Smart Community" initiative (see www.dec.ny.gov/energy/50845.html). This initiative encourages municipalities and businesses to jointly form strategies for mitigation while also raising awareness of public health officials for coordinated effort to approach climate change.

Nongovernmental organizations are generating fact sheets and briefing reports on health preparedness for inevitable climate change. The goal is to inform policy discussions and to encourage win-win efforts. There are also efforts to transcend the artificial divide in much legislation between ecosystem and human health. The general perception by these stakeholders was that thinking about climate change and the future risks it poses provides an opportunity to improve our current level of preparedness.

Stakeholders

Natural Resources Defense Council
NYC Department of Health and Mental Hygiene
NYC Office of the Mayor NYS Department of Health
NYS Department of Environmental Conservation
New York State Association of County and City Health Officials (NYSACCHO)
U.S. Environmental Protection Agency Region II
WE ACT for Environmental Justice

Survey of City and County Health Department Directors across New York State

This part of ClimAID stakeholder engagement involved administering an online survey to New York State county health officials. This survey was adapted from the 2007 national survey of city and county health department directors—"Are We Ready?"—which revealed critical gaps between expected climate-related health impacts and local health department capacity to respond. The 2007 national survey results included evidence that 1) the majority of respondents believe that climate change already has and will continue to represent significant health threats in their jurisdiction; 2) a majority perceived lack of knowledge and expertise at all levels; 3) there is minimal incorporation of long-range weather and climate projections; and 4) a majority call for increased funding, staff and training (Maibach et al., 2008).

Climate-related health outcomes were included for specific questions pertaining to perceived current or future threats and adaptation capacity: heat-related illness, hurricanes and floods, droughts, vector-borne infectious disease, water- and food-borne disease, water supply and quality, mental health conditions, and services and infrastructure for populations affected by extreme events. While nearly all departments had some programmatic activity in one of the climate-health categories included, few indicated that they had new programming areas planned. General questions about programming activity levels, knowledge capacity, and resource needs were stratified by climate-related health driver, such as heat waves and disease vectors. Results of the New York State survey are comparable to the national survey and generate meaningful insights into local preparedness infrastructure and needs.

As part of the ClimAID project, city and county health department directors were invited to participate in a statewide replication of this national survey during the winter of 2009–2010. The "Are We Ready?" survey instrument was adapted for online administration and distributed to all department directors. The survey questions are included at the end of this section. A letter of support from the National Association of County and City Health Officials (NACCHO) and the New York State Association of County and the City Health Officials encouraged officials to participate. Responses were anonymous and have no geographic identifiers.

The survey had an overall participation rate of 39 percent. While 57 percent of respondents agreed that climate change would affect their local area in the next 20 years, only 39 percent thought that climate change would cause health problems during that same time period. However, the majority (79 percent) disagreed or strongly disagreed that their local health department had "ample" expertise to assess the impacts of climate change in their jurisdiction. And over 70 percent of respondents reported no use of long-range weather or climate information in their departments' planning.

Among respondents who believed that climate-sensitive health impacts would stay the same or increase over the next 20 years, the following were cited as areas of perceived threat:

- heat waves and heat-related illnesses
- storms, including hurricanes and floods
- droughts, forest fires, or brush fires
- vector-borne infectious diseases
- water- and food-borne diseases
- anxiety, depression, or other mental health conditions
- quality or quantity of freshwater available
- quality of the air, including air pollution
- unsafe or ineffective sewage and septic system operation
- housing for residents displaced by extreme weather events
- healthcare services for people with chronic conditions during service disruptions, such as extreme weather events
- food security
- shoreline damage/loss of shoreline/wetlands/ groundwater and saltwater interaction
- severe cold and ice

As permitted by the survey, respondents could choose more than one area of concern regarding the health impacts of climate change. Heat-related health impacts were selected by 30 percent of respondents and storms by 33 percent, vector-borne disease by 56 percent, and air quality changes by 22 percent. Planned and active adaptation programming for these same four areas were reported as heat-related health programs in 33 percent of jurisdictions, storms in 54 percent of jurisdictions, vector-borne disease in 63 percent, and air quality adaptation programming in 25 percent. Of note, these percentages were all less than when respondents simply reported on current program activity in these same four areas. Of those that had a planned or active program in one of these areas, 5 percent deemed the allocated budget insufficient.

Two quotes from survey respondents that speak to the constraints regarding some of these issues:

> "With the current fiscal crisis in our region we are challenged to achieve basic health department mandated functions. We also do not have the

expertise to address this issue nor the funds to expand the programs we currently run."

"The local health department has not traditionally had a primary response role to environmentally related issues although we do support the emergency services department. While we understand that this is a role that public health should have, current fiscal restraints prevent us from being able to address climate change health effects in a suitable manner. Issues with food, water, etc. are covered by New York State Dept. of Health."

Overall, the New York State respondents showed a similar variety of concerns as the national sample though a smaller percentage deemed climate change a current or future threat to the health of residents in their jurisdiction. A non-respondent analysis is currently being explored to address the potential for generalizing these findings.

Survey Questions

Background	
1.	What is your position at your health department?
2.	What is the approximate annual budget for your health department?
3.	Approximately how many staff members in full-time equivalents does your health department have?
Climate change	
4.	People have different ideas about what climate change is. In your own words, what do you think the term “climate change” means?
Knowledge	
5a.	I am knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
5b.	The other relevant senior managers in my health department are knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
5c.	Many of the other relevant appointed officials in my jurisdiction outside of the public health system—such as environmental, agricultural, forestry and wildlife, energy and transportation officials—are knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
5d.	Many of the relevant elected officials in my jurisdiction are knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
5e.	Many of the business leaders in my jurisdiction are knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
5f.	Many of the leaders of the health care delivery system in my jurisdiction— including the hospitals and medical groups—are knowledgeable about the potential public health impacts of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
Perception	
6a.	My jurisdiction has experienced climate change in the past 20 years.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
6b.	My jurisdiction will experience climate change in the next 20 years.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
6c.	In the next 20 years, it is likely that my jurisdiction will experience one or more serious public health problems as a result of climate change.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
6d.	My health department currently has ample expertise to assess the potential public health impacts associated with climate change that could occur in my jurisdiction.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
6e.	Preparing to deal with the public health effects of climate change is an important priority for my health department.
	○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don’t know
7a.	Would you say that preventing or preparing for the public health consequences of climate change is among your health department’s top ten current priorities?
	○ Yes ○ No ○ Don’t know
7b.	(If Yes for Q7a) Which number—from one to ten, with one being the highest priority—would you say best characterizes the priority given to climate change currently in your health department?
Programmatic activity	
8.	Are the following health issues currently areas of programmatic activity for your health department?
	a. Heatwaves and heat-related illnesses? ○ Yes ○ No ○ Don’t know
	b. Storms, including hurricanes and floods? ○ Yes ○ No ○ Don’t know
	c. Droughts, forest fires or brush fires? ○ Yes ○ No ○ Don’t know
	d. Vector-borne infectious diseases? ○ Yes ○ No ○ Don’t know
	e. Water- and food-borne diseases? ○ Yes ○ No ○ Don’t know
	f. Anxiety, depression or other mental health conditions? ○ Yes ○ No ○ Don’t know
	g. Quality or quantity of fresh water available to your jurisdiction? ○ Yes ○ No ○ Don’t know
	h. Quality of the air, including air pollution, in your jurisdiction? ○ Yes ○ No ○ Don’t know
	i. Unsafe or ineffective sewage and septic system operation? ○ Yes ○ No ○ Don’t know
	j. Food safety and security? ○ Yes ○ No ○ Don’t know
	k. Housing for residents displaced by extreme weather events? ○ Yes ○ No ○ Don’t know
	l. Health care services for people with chronic conditions during service disruptions, such as extreme weather events?
	○ Yes ○ No ○ Don’t know
9a.	Are there other possible health effects associated with climate change in your jurisdiction that I have not mentioned?
	○ Yes ○ No ○ Don’t know
9b.	(If Yes for Q9a) What are those health effects?
9c.	(If Yes for Q9a) Is this health issue currently an area of programmatic activity for your department?
	○ Yes ○ No ○ Don’t know

10a. Does your health department use long-range weather or climate information in planning or implementing any programmatic activities?

○ Yes ○ No ○ Don't know

10b. (If Yes for Q10a) Do you use long-range weather or climate information in your planning or implementation of (each of the health issues a–l listed above)?

○ Yes ○ No ○ Don't know

11. Do you think climate change has already affected (each of the health issues a–l listed above) in your jurisdiction?

○ Yes ○ No ○ Don't know

12. Do you think that over the next 20 years climate change will likely make (each of the health issues a–l listed above) more common or severe, less common or severe, or that the problem will remain the same in your jurisdiction over the next 20 years?

○ More common or severe ○ Less common or severe ○ Remain the same ○ Don't know

13. Which of the potential health impacts of climate change that we have discussed, if any, are of greatest concern to you as a public health official? Feel free to name up to three outcomes.

14. Which of these three is your greatest concern? And which is your second greatest concern?

Adaptation expertise

15a. My health department currently has ample expertise to create an effective climate change adaptation plan.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

15b. My state health department currently has ample expertise to help us create an effective climate change adaptation plan in this jurisdiction.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

15c. The Centers for Disease Control and Prevention currently has ample expertise to help us create an effective climate change adaptation plan in this jurisdiction.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

15d. The health care delivery system in my jurisdiction—including the hospitals and medical groups—has ample expertise to create an effective climate change adaptation plan.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

Adaptation plans

16. Is your health department currently incorporating, planning to incorporate or not planning to incorporate adaptation into your programs for (each of the health issues a–l listed above)?

○ Currently incorporating ○ Planning to incorporate ○ Neither currently nor planning to incorporate ○ Don't know

17. How many staff members—in full-time equivalents—does/will this program have?

18. What is/will be the annual budget for this program?

19. In your opinion, is this an adequate level of funding for the program?

○ Yes ○ No ○ Don't know

The following question only asked if the response to Q16 was "currently":

20. Next year, will the annual budget for this program increase, decrease or remain about the same?

○ Increase ○ Decrease ○ Remain the same ○ Don't know

Mitigation expertise

21a. My health department currently has ample expertise to create an effective climate change mitigation plan.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

21b. My state's health department currently has ample expertise to help us create an effective climate change mitigation plan in this jurisdiction.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

21c. The Centers for Disease Control and Prevention currently has ample expertise to help us create an effective climate change mitigation plan in this jurisdiction.

○ Strongly disagree ○ Disagree ○ Agree ○ Strongly agree ○ Don't know

Mitigation plans

22. Does your department currently have, plan to have, or not have nor plan to have programs focused on the following activities?

a. Mitigating climate change by reducing greenhouse gas emissions from the health department?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

b. Helping residents of your jurisdiction reduce their greenhouse gas emissions?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

c. Reducing fossil fuel use or conserving energy in the operation of the health department?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

d. Helping residents of your jurisdiction reduce their fossil fuel use or conserve energy?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

e. Encouraging or helping people to use active transportation such as walking or cycling?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

f. Encouraging or helping people to use mass transportation?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

g. Encouraging or helping people to change the way they purchase foods such as buying locally grown foods, organic foods or plant-based foods?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

h. Educating the public about climate change and its potential impact on health?

○ Currently have ○ Plan to have ○ Neither currently nor plan to have ○ Don't know

23a.	Are there other activities associated with climate change mitigation in your jurisdiction that I have not mentioned?				
	○ Yes	○ No	○ Don't know		
23b.	(If Yes for Q23a) What are those activities?				
23c.	(If Yes for Q23a) Is this a current, future or not an area of programmatic activity for your department?				
	○ Yes	○ No	○ Don't know		
The following questions only asked if the response to Q22 was "currently" or "planning":					
24.	How many staff members—in full-time equivalents—does/will this program have?				
25.	What is/will be the annual budget for this program?				
26.	In your opinion, is this an adequate level of funding for the program?				
	○ Yes	○ No	○ Don't know		
The following question was only asked if the response to Q22 was "currently":					
27.	Next year, will the annual budget for this program increase, decrease or remain about the same?				
	○ Increase	○ Decrease	○ Remain the same	○ Don't know	
Regulatory role					
28.	Does your health department have any regulatory responsibility for the following functions?				
	a. Water supply and quality?	○ Yes	○ No	○ Don't know	
	b. Air quality?	○ Yes	○ No	○ Don't know	
	c. Food safety and security?	○ Yes	○ No	○ Don't know	
	d. Sewage or septic systems?	○ Yes	○ No	○ Don't know	
	e. Health care services?	○ Yes	○ No	○ Don't know	
	f. Mental health services?	○ Yes	○ No	○ Don't know	
	g. Housing code?	○ Yes	○ No	○ Don't know	
Resources					
29a.	Are there resources that your department does not currently have that, if made available, would significantly improve its ability to deal with climate change as a public health issue?				
	○ Yes	○ No	○ Don't know		
29b.	(If Yes for Q29a) What are those resources?				
	○ Additional Staff	○ Staff Training	○ Equipment	○ Budget/Money/Funding	○ Other
Respondents were asked to describe their answers in further detail:					
	a. How many additional staff and what would they do?				
	b. What kind of training?				
	c. What kind of equipment?				
	d. How much money and what would you use it for?				
Conclusion					
	Is there anything else that will help us understand the public health response to climate change in your jurisdiction?				

Appendix B. Technical Information on Heat Wave Cost

Year	Event Type	Region Affected	Sector(s) Most Affected	Total Costs / Damage Costs (billion $)	Deaths
2000	Severe drought & persistent heat	South-central & southeastern states	agriculture and related industries	$4.2	140
1998	Severe drought & persistent heat	TX / OK eastward to the Carolinas	agriculture and ranching	$6.6–9.9	200
1993	Heat wave/drought	Southeast US	agriculture	$1.3	16
1988	Heat wave/drought	Central & Eastern US	agriculture & related industries	$6.6	5000–10,000
1986	Heat wave/drought	Southeast US	agriculture & related industries	$1.8–2.6	100
1980	Heat wave/drought	Central & Eastern US	unspecified	$48.4	10,000

Source: Ross and Lott, 2003

Table 11.5 Costs for major heat waves in the United States

Appendix C. Annotated Heat-Mortality, Wildfires, and Air Pollution Methods References

Anderson, B. G. and M. L. Bell. 2009. "Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States." *Epidemiology* 20(2):205–213.
Background:
Many studies have linked weather to mortality; however, the role of such critical factors as regional variation, susceptible populations, and acclimatization remain unresolved.
Methods:
They applied time-series models to 107 U.S. communities allowing a nonlinear relationship between temperature and mortality by using a 14-year dataset. Second-stage analysis was used to relate cold, heat, and heat-wave effect estimates to community-specific variables. They considered exposure timeframe, susceptibility, age, cause of death, and confounding effects of pollutants. Heat waves were modeled with varying intensity and duration.
Results:
Heat-related mortality was most associated with a shorter lag (average of same day and previous day), with an overall increase of 3.0 percent (95 percent posterior interval: 2.4 percent–3.6 percent) in mortality risk comparing the 99th and 90th percentile temperatures for the community. Cold-related mortality was most associated with a longer lag (average of current day up to 25 days previous), with a 4.2 percent (3.2 percent–5.3 percent) increase in risk comparing the first and 10th percentile temperatures for the community. Mortality risk increased with the intensity or duration of heat waves. Spatial heterogeneity in effects indicates that weather-mortality relationships from one community may not be applicable in another. Larger spatial heterogeneity for absolute temperature estimates (comparing risk at specific temperatures) than for relative temperature estimates (comparing risk at community-specific temperature percentiles) provides evidence for acclimatization. They identified susceptibility based on age, socioeconomic conditions, urbanicity, and central air conditioning.
Conclusions:
Acclimatization, individual susceptibility, and community characteristics all affect heat-related effects on mortality.

Hoyt, K. S. and A. E. Gerhart. 2004. "The San Diego County wildfires: perspectives of healthcare providers [corrected]." *Disaster Management and Response* 2(2):46–52.
The wildfires of October 2003 burned a total of 10 percent of the county of San Diego, California. Poor air quality contributed to an increased number of patients seeking emergency services, including healthcare providers affected by smoke and ash in hospital ventilation systems. Two large hospitals with special patient populations were threatened by rapidly approaching fires and had to plan for total evacuations in a very short time frame. A number of medical professionals were forced to prioritize responding to the hospital's call for increased staff during the disaster and the need to evacuate their own homes.

Johnston, F. H., A. M. Kavanagh, et al. 2002. "Exposure to bushfire smoke and asthma: an ecological study." *Medical Journal of Australia* 176(11):535–538.
Objective:
To examine the relationship between the mean daily concentration of respirable particles arising from bushfire smoke and hospital presentations for asthma.
Design and Setting
An ecological study conducted in Darwin (Northern Territory, Australia) from 1 April–31 October 2000, a period characterised by minimal rainfall and almost continuous bushfire activity in the proximate bushland. The exposure variable was the mean atmospheric concentration of particles of 10 microns or less in aerodynamic diameter (PM_{10}) per cubic metre per 24-hour period.
Outcome Measure:
The daily number of presentations for asthma to the Emergency Department of Royal Darwin Hospital.
Results:
There was a significant increase in asthma presentations with each $10 \mu g/m^3$ increase in PM_{10} concentration, even after adjusting for weekly rates of influenza and for weekend or weekday (adjusted rate ratio, 1.20; 95 percent confidence interval (CI), 1.09–1.34; $P < 0.001$). The strongest effect was seen on days when the PM_{10} was above $40 \mu g/m^3$ (adjusted rate ratio, 2.39; 95 percent confidence interval (CI), 1.46–3.90), compared with days when PM_{10} levels were less than $10 \mu g/m^3$.
Conclusions:
Airborne particulates from bushfires should be considered as injurious to human health as those from other sources. Thus, the control of smoke pollution from bushfires in urban areas presents an additional challenge for managers of fireprone landscapes.

Kinney, P. L. and H. Ozkaynak. 1991. "Associations of daily mortality and air pollution in Los Angeles County." *Environmental Research* 54(2):99–120.
They report results of a multiple regression analysis examining associations between aggregate daily mortality counts and environmental variables in Los Angeles County, California for the period 1970 to 1979.
Methods:
Mortality variable included total deaths not due to accidents and violence (M), deaths due to cardiovascular causes (CV), and deaths due to respiratory causes (Resp). The environmental variables included five pollutants averaged over Los Angeles County: total oxidants (Ox), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and KM (a measure of particulate optical reflectance). Also included were three metereological variables measured at the Los Angeles International Airport: temperature (Temp), relative humidity (RH), and extinction coefficient (B_{ext}), the latter estimated from noontime visual range. To reduce the possibility of spurious correlations arising from the shared seasonal cycles of mortality and environmental variables, seasonal cycles were removed from the data by applying a high-pass filter. Cross-correlation functions were examined to determine the lag structure of the data prior to specifying and fitting the multiple regression models relating mortality and the environmental variables.
Results:
The results demonstrated significant associations of M (or CV) with Ox at lag 1, temperature, and NO_2, CO, or KM. Each of the latter three variables was strongly associated with daily mortality but all were also highly correlated with one another in the high-frequency band, making it impossible to uniquely estimate their separate relationships to mortality
Conclusions:
The results of this study show that small but significant associations exist in Los Angeles County between daily mortality and three separate environmental factors: temperature, primary motor vehicle-related pollutants (e.g., CO, KM, NO_2), and photochemical oxidants.

Levy, J. I., S. M. Chemerynski, et al. 2005. “Ozone exposure and mortality: an empiric Bayes metaregression analysis.” *Epidemiology* 16(4): 458–468.
Background:
Results from time-series epidemiologic studies evaluating the relationship between ambient ozone concentrations and premature mortality vary in their conclusions about the magnitude of this relationship, if any, making it difficult to estimate public health benefits of air pollution control measures. Authors conducted an empiric Bayes metaregression to estimate the ozone effect on mortality, and to assess whether this effect varies as a function of hypothesized confounders or effect modifiers.
Methods:
They gathered 71 time-series studies relating ozone to all-cause mortality, and they selected 48 estimates from 28 studies for the metaregression. Metaregression covariates included the relationship between ozone concentrations and concentrations of other air pollutants, proxies for personal exposure-ambient concentration relationships, and the statistical methods used in the studies. For the metaregression, they applied a hierarchical linear model with known level-1 variances.
Results:
They estimated a grand mean of a 0.21 percent increase (95 percent confidence interval = 0.16–0.26 percent) in mortality per 10-$\mu g/m^3$ increase of 1-hour maximum ozone (0.41 percent increase per 10 ppb) without controlling for other air pollutants. In the metaregression, air-conditioning prevalence and lag time were the strongest predictors of between-study variability. Air pollution covariates yielded inconsistent findings in regression models, although correlation analyses indicated a potential influence of summertime $PM_{2.5}$.
Conclusions:
These findings, coupled with a greater relative risk of ozone in the summer versus the winter, demonstrate that geographic and seasonal heterogeneity in ozone relative risk should be anticipated, but that the observed relationship between ozone and mortality should be considered for future regulatory impact analyses.

O'Neill, M. S., A. Zanobetti, et al. 2003. “Modifiers of the temperature and mortality association in seven US cities.” *American Journal of Epidemiology.* 157(12):1074–1082.
This paper examines effect modification of heat- and cold-related mortality in seven U.S. cities in 1986–1993.
Methods:
City-specific Poisson regression analyses of daily noninjury mortality were fit with predictors of mean daily apparent temperature (a construct reflecting physiologic effects of temperature and humidity), time, barometric pressure, day of the week, and particulate matter less than 10 micro m in aerodynamic diameter. Percentage change in mortality was calculated at 29°C apparent temperature (lag 0) and at -5°C (mean of lags 1, 2, and 3) relative to 15°C. Separate models were fit to death counts stratified by age, race, gender, education, and place of death. Effect estimates were combined across cities, treating city as a random effect.
Results:
Deaths among Blacks compared with Whites, deaths among the less educated, and deaths outside a hospital were more strongly associated with hot and cold temperatures, but gender made no difference. Stronger cold associations were found for those less than age 65 years, but heat effects did not vary by age. The strongest effect modifier was place of death for heat, with out-of-hospital effects more than five times greater than in-hospital deaths, supporting the biologic plausibility of the associations.
Conclusions:
Place of death, race, and educational attainment indicate vulnerability to temperature-related mortality, reflecting inequities in health impacts related to climate change.

Peel, J. L., K. B. Metzger, et al. 2007. “Ambient air pollution and cardiovascular emergency department visits in potentially sensitive groups.” *American Journal of Epidemiology* 165(6):625-633.
Limited evidence suggests that persons with conditions such as diabetes, hypertension, congestive heart failure, and respiratory conditions may be at increased risk of adverse cardiovascular morbidity and mortality associated with ambient air pollution.
Methods:
The authors collected data on over four million emergency department visits from 31 hospitals in Atlanta, Georgia, between January 1993 and August 2000. Visits for cardiovascular disease were examined in relation to levels of ambient pollutants by use of a case-crossover framework. Heterogeneity of risk was examined for several comorbid conditions.
Results:
The results included evidence of stronger associations of dysrhythmia and congestive heart failure visits with comorbid hypertension in relation to increased air pollution levels compared with visits without comorbid hypertension; similar evidence of effect modification by diabetes and chronic obstructive pulmonary disease (COPD) was observed for dysrhythmia and peripheral and cerebrovascular disease visits, respectively. Evidence of effect modification by comorbid hypertension and diabetes was observed in relation to particulate matter less than 10 microm in aerodynamic diameter, nitrogen dioxide, and carbon monoxide, while evidence of effect modification by comorbid COPD was also observed in response to ozone levels.
Conclusions:
These findings provide further evidence of increased susceptibility to adverse cardiovascular events associated with ambient air pollution among persons with hypertension, diabetes, and COPD.

Peel, J. L., P. E. Tolbert, et al. 2005. “Ambient air pollution and respiratory emergency department visits.” *Epidemiology* 16(2):164-174.
Background:
A number of emergency department studies have corroborated findings from mortality and hospital admission studies regarding an association of ambient air pollution and respiratory outcomes. More refined assessment has been limited by study size and available air quality data.
Methods:
Measurements of five pollutants (particulate matter [PM_{10}], ozone, nitrogen dioxide [NO_2], carbon monoxide [CO], and sulfur dioxide [SO_2]) were available for the entire study period (1 January 1993 to 31 August 2000); detailed measurements of particulate matter were available for 25 months. Authors obtained data on four million emergency department visits from 31 hospitals in Atlanta. Visits for asthma, chronic obstructive pulmonary disease, upper respiratory infection (URI), and pneumonia were assessed in relation to air pollutants using Poisson generalized estimating equations.
Results:
In single-pollutant models examining three-day moving averages of pollutants (lags 0, 1, and 2): standard deviation increases of

ozone, NO_2, CO, and PM_{10} were associated with 1–3 percent increases in URI visits; a 2 μg/m increase of $PM_{2.5}$ organic carbon was associated with a 3 percent increase in pneumonia visits; and standard deviation increases of NO_2 and CO were associated with 2–3 percent increases in chronic obstructive pulmonary disease visits. Positive associations persisted beyond three days for several of the outcomes, and over a week for asthma.

Conclusions:

The results of this study contribute to the evidence of an association of several correlated gaseous and particulate pollutants, including ozone, NO_2, CO, PM, and organic carbon, with specific respiratory conditions.

Westerling, A. L., H. G. Hidalgo, et al. 2006. "Warming and earlier spring increase western U.S. forest wildfire activity." *Science* 313(5789): 940–943.

Background:

Western United States forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfires has been systematically documented. Much of the public and scientific discussion of changes in western United States wildfires has focused instead on the effects of 19th- and 20th-century land-use history.

Methods:

They compiled a comprehensive database of large wildfires in western United States forests since 1970 and compared it with hydroclimatic and land-surface data.

Results:

Here, the authors show that large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Chapter 12

Conclusions and Recommendations

Contents

Climate Change and New York State

Adapting to a changing climate is challenging in New York State due to its diverse nature geographically, economically, and socially. The main drivers of climate change impacts—higher temperature, sea level rise and its potential to increase coastal flooding, and changes in precipitation—will have a wide variety of effects on the sectors and regions across the state and will engender a wide range of adaptation strategies. Climate change will bring opportunities as well as constraints, and interactions of climate change with other stresses, such as population growth, will create new challenges.

While New York State ranks 27th among the states in area (54,556 square miles, including 7,342 square miles of inland water), it is subject to a much wider range of climate impacts than its size in square miles would suggest. The north-to-south distance from the Canadian border to the tip of Staten Island is over 300 miles; from east to west (from the longitude of the eastern tip of Long Island to the longitude of the western border of New York State at Lake Erie), the distance is over 400 miles. Further diversity stems from the presence of the densely populated New York City, while much of the state is rural in character. Thus, climate hazards are likely to produce a range of impacts on the rural and urban fabric of New York State in the coming decades.

The adaptation strategies described in the ClimAID Assessment could be useful in preparing for and responding to climate risks now and in the future. Such adaptation strategies are also likely to produce benefits today, since they will help to lessen impacts of climate extremes that currently cause damage. However, given the scientific uncertainties in projecting future climate change, monitoring of climate and impacts indicators is critical so that flexible adaptation pathways for the region can be achieved over time.

This chapter summarizes the overall conclusions and recommendations of the ClimAID assessment. They focus on the five integrating themes (climate, vulnerability, adaptation, equity and environmental justice, and economics) and the eight sectors (Water Resources, Coastal Zones, Ecosystems, Agriculture, Energy, Transportation, Telecommunications, and Public Health). The conclusions and recommendations highlight sectoral, geographical, and temporal dimensions in responding to the risks posted by climate change in New York State.

Integrating Themes

This section highlights the conclusions focused on the five integrating themes.

Climate

The humid continental climate of New York State varies from warmer to cooler and from wetter to dryer regions. The weather that New York State has experienced historically provides a context for assessing climate changes that are projected for the rest of the century. The ClimAID Assessment found that much of the state is already warming and that projected climate changes in temperature and other variables could bring significant impacts.

Observed Climate Trends

Observed climate trends include the following:

- Annual temperatures have been rising throughout the state since the start of the 20th century. State-average temperatures have increased by approximately 0.6ºF per decade since 1970, with winter warming exceeding 1.1ºF per decade.
- Since 1900, there has been no discernable trend in annual precipitation, which is characterized by large interannual and interdecadal variability.
- Sea level along New York's coastline has risen by approximately 1 foot since 1900.
- Intense precipitation events (heavy downpours) have increased in recent decades.

As a whole, New York State has experienced a significant warming trend over the past three to four decades. Sea level along New York's coastline has increased approximately 12 inches over the past century. Given these trends and projections of future changes, past climate will likely be a less consistent predictor of future climate, and, in turn, reliance on past climate records may not suffice as benchmarks for forecasting.

Climate Projections

In regard to projections, climate change is extremely likely to bring higher temperatures to New York State, with slightly larger increases in the north of the state than along the coastal plain (See **Table 12.1** for definitions of likelihood used in the ClimAID Assessment). Heat waves are very likely to become more frequent, more intense, and longer in duration.

Total annual precipitation will more likely than not increase, likely occurring as more frequent intense rainstorms. Summer droughts could increase in frequency, intensity, and duration, especially as the century progresses. Meanwhile, there will likely be a reduction in snowpack and an increase in the length of the growing season.

Additionally, rising sea levels are extremely likely and are very likely to lead to more frequent and damaging flooding along the shores and estuaries of New York State related to coastal storm events in the future.

However, significant uncertainties exist about future climate risks due to difficulties in projecting greenhouse gas emissions and imprecise understanding of climate sensitivity to greenhouse gas forcing, among other factors.

Projected changes in mean climate

Projections of mean climate changes include the following:

- Mean temperature increase is extremely likely this century. Downscaled results from global climate models with a range of greenhouse gas emissions scenarios indicate that temperatures across New York State[1] may increase 1.5–3.0°F by the 2020s,[2] 3.0–5.5°F by the 2050s, and 4.0–9.0°F by the 2080s.

Likelihood	Probability of occurrence
Extremely likely	>95% probability of occurrence
Very likely	>90% probability of occurrence
Likely	>66% probability of occurrence
More likely than not	>50% probability of occurrence

Table 12.1 Likelihood and probability of occurrence

- While most downscaled results for New York State from global climate models project a small increase in annual precipitation, interannual and interdecadal variability are expected to continue to be large. Projected precipitation increases are largest in winter, and small decreases may occur in late summer/early fall.
- Rising sea levels are extremely likely this century. Sea level rise projections for the coast and tidal Hudson River, based on GCM-based methods, are 1–5 inches by the 2020s, 5–12 inches by the 2050s, and 8–23 inches by the 2080s.
- There is a possibility that sea level rise may exceed projections based on GCM-based methods, if the melting of the Greenland and West Antarctic Ice Sheets continues to accelerate. A rapid ice-melt scenario, based on observed rates of melting and paleoclimate records, yields sea level rise of 37–55 inches by the 2080s.

Changes in climate variability and extreme events

Climate variability refers to temporal fluctuations about the mean at daily, seasonal, annual, and decadal timescales. The quantitative projection methods in the ClimAID Assessment generally assume climate variability will remain unchanged as long-term average conditions shift. As a result of changing long-term averages alone, some types of extreme events are projected to become more frequent, longer, and intense (e.g., heat events), while events at the other extreme (e.g., cold events) are projected to decrease. Projected changes in extreme climate events include the following:

- Extreme heat events are very likely to increase and extreme cold events are very likely to decrease throughout New York State.
- Intense precipitation events are likely to increase. Short-duration warm season droughts will more likely than not become more common.
- Coastal flooding associated with sea level rise is very likely to increase.

In the case of brief intense rain events (for which only qualitative projections can be provided), both the mean and variability are projected to increase, based on a combination of global and regional climate model

[1] The range of temperature projections is the lowest and highest of values across the middle 67 percent of projections for all regions of New York State.

[2] The temperature and precipitation timeslices reflect a 30-year average centered around the given decade, i.e., the time period for the 2020s is from 2010–2039. For sea level rise, the timeslice represents a 10-year average.

simulations, process-based understanding, and observed trends. Both heavy precipitation events and warm-season droughts (which depend on several climate variables) are projected to become more frequent and intense during this century.

Whether extreme multi-year droughts will become more frequent and intense than at present is a question that is not fully answerable today. Historical observations of large interannual precipitation variability suggest that extreme drought at a variety of timescales will continue to be a risk for the region during the 21st century.

Vulnerability

Impacts associated with climate changes are projected to be felt in a wide range of sectors and regions. How vulnerability is manifested depends on the magnitude of the impacts (e.g., the area or number of people affected) and the intensity (e.g., the degree of damage caused). Timing is also critical: Is the impact expected to happen in the near term or in the distant future? Are rare events becoming more frequent? And are impacts reversible over the timescale of generations? Other key aspects of vulnerability include the potential for adaptation and potential thresholds or trigger points that could exacerbate the change.

Sectoral Dimensions

Climate change impacts will be directly connected with ongoing transitions within the state, such as population growth and economic development. See **Table 12.2** for key sector-related vulnerabilities. Climate change in many cases will alter the functioning of the state's key sectors by causing shifts within its physical and social systems. For example, climate change is already resulting, and will very likely continue to result, in north-to-south shifts in the state's ecoregions. Thus, there is a clear need for ecosystem management approaches that focus on preserving diversity, rather than on protection of individual species.

The impacts of climate change on water and agricultural resources present both potential challenges and opportunities for the state. New York State water managers and farmers will face increased climate variability and potential for times of water stress. Opportunities for the state could emerge vis-à-vis the development of new crops and modes of agricultural production associated with underused agricultural land and potential water supply. For example, in comparison to many other states, New York's current and projected relative wealth of water resources, if properly managed, can contribute to resilience and new economic opportunities. Opportunities to explore new varieties, new crops, and new markets may come with higher temperatures and longer growing seasons.

The energy and public health sectors also will experience shifts in climate risks. In both cases, sector managers will likely face greater climate variability and system stress from more frequent and intense extreme events such as heat waves. The shifts in climate will both exacerbate existing risks and create new risks, such as increased fatigue on equipment and outbreaks of diseases previously not widely seen.

Overall, the climate risk associated with sea level rise is a key pressing impact for the state in terms of dollars associated with both impacts and adaptation. Its impacts will cut across many sectors, from ecosystems to critical infrastructure (e.g., for water, energy, transportation, and communication) and public health. More frequent extreme events such as heat waves and heavy downpours, as well as gradual climate shifts, will increase the amount of climate risk faced by critical transportation and telecommunication infrastructure throughout the state.

Geographic Dimensions

Climate change impacts will be felt across the entire state. Coastal zone communities, populations, and ecosystems face significant risks and potential damages from sea level rise and enhanced coastal flooding. A critical task is the determination of the shift in the extent of the 1-in-100-year flood zones (those areas designated as having a 1 percent probability of flooding any given year) and associated uncertainties.

Natural resource- and agriculture-dependent communities in rural areas will face both significant challenges and potential opportunities. Riverine communities may face increased risk of flooding from extreme rainfall events. Communities dependent on small-scale water supply systems may face water supply management issues. In urban areas, poor communities—especially in flood zones and in areas lacking in vegetation—may be less able to cope with extreme rainfall events.

Temporal Dimensions

Climate change already has begun in New York State. If greenhouse gas emissions continue unabated, the rate and magnitude of climate change are expected to increase over time. Establishing an ongoing monitoring system and strengthening climate science capabilities will provide enhanced opportunities for understanding and responding to future climate change.

Climate-change-related extreme events and system-level shifts could occur at any time. The risk of extreme events associated with high temperatures and intense precipitation events will likely increase, while intense cold waves will likely decrease. Natural and human systems in the state are thus subject to a variety of gradual and rapid transitions related to climate.

Table 12.2 Sector-specific Climate Change Vulnerability

Water Resources

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Infrastructure							
Precipitation	Increase in mean precipitation	More likely than not	N/A	New maximum potential stream flow/flooding in large basins	Uncertain	Increase in the number of moderate floods	Medium
				Urbanized watersheds rapidly aggregate water and have a limited capacity to attenuate rainfall inputs	Medium	Increase in the number of flash floods	High
				Increased flooding of wastewater treatment plants	Low	Routine interruption of operations for an extended time period	High
Sea Level Rise	Sea level rise	Very likely	N/A	Flooding of coastal water infrastructure, including wastewater treatment plants	Medium	Temporary or permanent disruption of service	High
Drinking Water Supply							
Temperature	Increase in mean temperature	Very likely	Increase in mean temperatures may be greater 1) in the north than south, and 2) in winter than in summer in the north	Increased demand	Low	Increased strain on system	Low
	Increase in extreme heat events	Likely	N/A				
Temperature / Precipitation	Drought	Uncertain	Toward the end of the century, warm season droughts will more likely than not increase	Changes in groundwater depths	High	Increased possibility of well depletion	High
				Seasonal variation in reservoir inflow and aquifer recharge	High	Decreased reliability of historical levels for planning	High
				Low wells, wells in moderately productive aquifers, and small reservoirs	Medium	These areas will have to tap into larger reservoir systems, increasing overall strain on systems	High
Precipitation	Increase in mean precipitation	More likely than not	N/A	Increased turbidity of water supply reservoirs	Medium	Decreased quality of water supplies (also see water quality section)	High
Commercial and Agriculture Water Availability							
Temperature	Increase in mean temperature	Very likely	Increase in mean temperatures may be greater 1) in the north than south, and 2) in winter than in summer in the north	Increased demand for crops and livestock and for cooling commercial infrastructure systems	Low	Increased strain on system	Low
	Increase in extreme heat events	Likely	N/A				
Temperature / Precipitation	Drought	Uncertain	Towards the end of the century, warm season droughts will more likely than not increase	Greater competition for water between potable, commercial uses, and ecological needs	Medium	Lessened dependence on hydroelectricity as an energy supply	Medium
				Decrease in availability of water resources for equipment cooling	High	Facilities turn to low-consumption, "once-through" cooling where water is returned to the same water body at a higher temperature, influencing aquatic organisms	Medium
				Increased consumption due to natural gas drilling in deep shales	Low	Withdrawals will not be spread uniformly across a basin and intensive withdrawals from smaller headwater streams may lead to localized low flows	Medium
Precipitation	Increase in mean precipitation	More likely than not	N/A	Increased turbidity of water supply reservoirs	Medium	Decreased quality of water supplies (also see water quality section)	High

Water Resources (continued)							
Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Water Quality							
Temperature	Increase in mean annual temperature	Very likely	Increase in mean temperatures may be greater 1) in the north than south, and 2) in winter than in summer in the north	Favorable corn-based ethanol production	Medium	May lead to increased agricultural land use in NYS	Medium
				Greater pathogen survivability in waters	High	Increased potential for disease in aquatic life	High
				Increased algal growth in water bodies as well as increased dissolved organic matter exported from soils and wetlands	High	Impairs recreational use and normal ecosystem function; increased organic matter may increase the concentration of disinfection by-products (DBP) in drinking water (potentially harmful chemicals that form when chlorine added to kill pathogens reacts with organic matter)	High
	Increase in water temperature of streams and rivers	Likely/ very likely	Depends on many factors besides air temperature, such as precipitation, water demand, and land cover	Warmer water holds less dissolved oxygen (DO), so warmer waters will increase strain on streams that already experience oxygen depletion	Medium	High DO levels are detrimental to aquatic organisms	Medium
Precipitation	Increase in mean annual precipitation	More likely than not	N/A	Expanded agriculture in water-rich areas	Medium	Increased nutrient (nitrogen and phosphorus) loading, which leads to degraded water quality and ecosystem health	Medium
	Increase in extreme precipitation events	More likely than not	N/A	Increased runoff and reduced infiltration of rain into natural ground cover and soils	High	Greater potential for CSOs	High

Notes: N/A = Not Applicable
CSO = Combined sewer overflow
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, “Adaptation Guidebook”)

Coastal Zones

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Infrastructure and Coastal Property							
Sea level rise	Permanent inundation of coastal areas	N/A	By 2050, only a small increase in the area permanently inundated is expected	Entrances to bridges, tunnels, segments of highways, wastewater treatment plants, and sewer outfall systems permanently under sea water	High	Failure of systems	High
				Coastal properties permanently under sea water	High	Abandonment of waterfront structures and residences (ground floor or potentially altogether)	Medium
				Increase in salinity of influent into wastewater pollution control plants	Medium	Corrosion of materials and equipment, failure of systems	High
	Increased frequency, intensity, and duration of storm surge and coastal flooding	Likely/very likely	Will depend both on sea level rise and on uncertain changes in tropical cyclones and nor'easters	Coastal property damage	High	Potential loss of life	High
						Economic impact	High
						Complications to evacuation routes	Medium
				Increased wear and tear on equipment not designed for salt-water exposure	Medium	Failure of systems	Medium
						More frequent delays and service interruptions on public transportation and low-lying highways	Medium
Ecosystems							
Temperature	Warmer coastal sea surface temperatures	Likely	N/A	Heightened disease, harmful algae blooms, and increased competition over resources	High	Ecosystem vulnerability	Medium
				Northward shift in range of habitat for many commercially important fish and shellfish species	High	Decline in fishing industry	High
Precipitation	Increased mean precipitation	More likely than not	N/A	Affect rates of groundwater recharge lake levels	Medium	Potential shortages of drinking water availability	High
				Increased or reduced stream flow	Medium	Affect the delivery of nutrients and pollutants to coastal waters potentially leading to poorer water quality	Medium
Sea level rise	Permanent inundation of coastal areas	N/A	By 2050, only a small increase in the area permanently inundated is expected	Permanent inundation of wetlands	High	Loss of critical wetland habitat	High
	Increased storm surge and coastal flooding	Likely/very likely	Will depend both on sea level rise and on uncertain changes in tropical cyclones and nor'easters	Increased beach erosion	High	Barrier migrations and loss of barrier islands resulting in exposure of the bay and mainland shoreline to more oceanic conditions	High
	Increased wave action	Likely	Will depend both on sea level rise and on uncertain changes in tropical cyclones and nor'easters	Erosion and reshaping of shorelines	Medium	Affect the location and extent of storm surge inundation	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, “Adaptation Guidebook”)

Ecosystems

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Plants							
Temperature	Increase in mean annual temperature	Very likely	Increase in mean temperatures may be greater 1) in the north than south, and 2) in winter than in summer in the north	Potential increase in plant growth with large differences between species	Medium	Altered plant community structure and potential for invasives	Low
	Warmer winters	Very likely	N/A	Longer growing season	Medium	Shift in ecosystems	High
				Earlier blooming of perennials	High	Potential to throw off symbiotic relationships	High
				Potential changes in sap flow	Medium	Negative effects on maple syrup production requiring some regions to increasingly rely on more expensive technology	High
Animals and Insects							
Temperature	Increase in mean annual temperature	Very likely	Increase in mean temperatures may be greater 1) in the north than south, and 2) in winter than in summer in the north	Insects see more generations per season	Medium	Rate of invasive and pest species rises	High
	Warming waters	Likely/very likely	Depends on air temperature, precipitation, water demand, and land cover	Decline in coldwater fish species such as brook trout and other native species	High	Changes in coldwater ecosystems	High
						Decline in fishing industry for coldwater species	Medium
	Warmer winters	Very likely	N/A	Northward shift in range of many species, including undesirable pests, diseases and vectors of disease, invasives	High	Changes in ecosystems, decline of native species	High
				Increased winter survival of deer populations	High	Increasing deer inflicted damage to plants	Medium
				Increased survival of marginally over-wintering insect pests	Medium	Increased pest threat to ecosystems	Medium
				Earlier arrival of migratory birds	High	Potential to throw off symbiotic relationships	High
	Reduction in snow cover	Unknown	Earlier snowmelt is likely/very likely	Negative effects on survival of animals and insects who depend on snow for insulation and protective habitat	High	Changes in ecosystems, decline of native species	High
				Increased winter deer feeding	High	Increased vegetation damage	Medium
Recreation							
Temperature	Reduction in snow cover	Unknown	Earlier snowmelt is likely/very likely	Less natural snow for ski industry	High	Smaller, more southerly or lower altitude ski operations may have more difficulty keeping up with increasing demands on artificial snowmaking capacity	Medium

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, “Adaptation Guidebook”)

Agriculture

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Crops							
Temperature	Increase in mean temperatures	Very likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Longer growing season for certain crops	High	Potentially increased crop yield and may expand market opportunity for some crops, but also prices go down	Medium
						Weeds will grow faster and will have to be controlled for longer periods	Medium
						Increased seasonal water and nutrient requirements	Medium
				Increased weed, disease, and insect pressure	Medium	Lower native crop survival, increase in prices	High
				Increased relative risk of freeze or frost damage and/or reduced winter chill-hour accumulation required for normal spring development	High	Lower survival of perennial fruit crops	High
				Weed species more resistant to herbicides	Low	Change in species composition potentially not favoring native crops	Medium
				Northward expansion of disease range and weeds (plants that have not built immunity to new pathogens are more susceptible to disease and larger populations of pathogens survive to initially infect plants)	High	Lower crop survival	High
				Crop damage due to sudden changes, such as increased freeze damage of woody plants due to loss of winter hardiness or premature leaf-out and frost damage	Medium	Decrease in crop yield	Medium
	Warmer winters	Very likely	N/A	Lengthened growing season	Medium	Could increase productivity or quality of some woody perennials (e.g., European wine grapes)	High
				Not enough freeze days for certain crops	Medium	By mid to late century, negatively affect crops adapted to current climate (e.g., Concord grape, some apple varieties)	Medium
				More winter cover crop options; depending on variability of winter temps, can lead to increased freeze or frost damage of woody perennials	Medium	Decrease in crop yield	Medium
	Increase in extreme heat events	Likely	N/A	Stress on crops, especially if extreme events occur in clusters	Medium to High	Major crop and profit loss	Medium to High
				Heat stress effects	High	Negatively affect yield or quality of many cool-season crops that currently dominate the ag economy, such as apple, potato, cabbage, and other cold crops	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, "Adaptation Guidebook")

Agriculture (continued)

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Crops (continued)							
Precipitation	Increase in mean precipitation	More likely than not	N/A	Increased flooding resulting in inability to access field during critical times	Medium	Direct crop damage, increased chemical contamination of waterways and harvested crops	Medium
				Increased flooding risk could delay spring planting and harvest	High	Negatively affect market prices; reduction in the high-value early season production of vegetable crops	High
				Increased soil compaction because of tractor use on wet soils	High	Increased vulnerability to future flooding and drought; increasing runoff and erosion; plants have difficulty in compacted soil because the mineral grains are pressed together leaving little space for air and water, which are essential for root growth	High
				Increased crop root disease and anoxia	High	Decrease in crop productivity and yield	High
				Wash-off of applied chemicals	Medium	Decrease in crop productivity and yield	High
	Increase in droughts	Uncertain	N/A	Decrease the duration of leaf wetness and reduce forms of pathogen attack on leaves	High	Decrease in crop productivity	High
				Increased stress on plants	High	Reduced yields and crop losses, particularly for rain-fed agriculture	Medium
				Inadequate irrigation capacity for some high value crop growers	High	Decrease in crop yield	Medium
				Dry streams or wells	Medium	Increased pumping costs from wells	Medium
	Increase in intense precipitation events	More likely than not	N/A	Stress on crops, especially if extreme events occur in clusters	Medium to High	Major crop and profit loss	Medium to High
	Changes in cloud cover and radiation	Uncertain	N/A	Cloudy periods during critical development stages impacts plant growth	High	Affect plant growth, yields, and crop water use	High
Livestock (Dairy)							
Temperature	Increase in extreme heat events	Likely	N/A	Increased stress to livestock	High	Decrease in milk production; reduced calving rates	Medium
Insects and Weed Pests							
Temperature	Increase mean temperatures	Very likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	More generations per season; shifts in species range	High	Increased vulnerability of crops to pests	High
	Warmer winters	Very likely	N/A	Increased spring populations of marginally overwintering insects Northward range expansion of invasive weeds	High	Increased vulnerability of crops to pests and invasives	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, "Adaptation Guidebook")

Energy

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Energy Resources							
Temperature	Increased mean temperatures	Very Likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Changes in biomass available for energy generation	Medium	Decreased reliability of biomass as an alternative energy source	Low
Precipitation	Increases in mean precipitation	More likely than not	N/A	Availability of hydropower reduced	Medium	Decreased reliability of hydropower as an alternative energy source	Low
	Cloud cover	Uncertain	N/A	Changes in solar exposure	High	Decreased reliability of solar power as an alternative energy source	Low
Extreme events	Wind	Uncertain	N/A	Availability and predictability is reduced with variation in wind	High	Decreased reliability of wind energy as an alternative energy source	Low
Generation Assets							
Temperature	Increase in mean temperatures	Very Likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Reduced water cooling capacity	Medium	Water-cooled nuclear power plants become more at risk for overheating and failure of equipment; the thermal efficiency of power generation is reduced	High
Sea level rise	Increased frequency, intensity, and duration of storm surge and coastal flooding	Likely/very likely	Will depend both on sea level rise and on uncertain changes in tropical cyclones and Nor'easters	Damage to coastal power plants	High	Reduced generation	Medium
Transmission and Distribution Assets							
Temperature	Increase in mean temperatures	Very Likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Sagging power lines	Medium	More frequent power outages	Medium
				Wear on transformers	Medium	Transformers rated for particular temperatures may fail more frequently	Medium
Precipitation	Snow storms	Uncertain	N/A	Transmission infrastructure damage	Low	Changes in power outage frequency	Medium
	Ice storms	Uncertain	N/A	Transmission lines sagging due to freezing/collecting ice	Low	Changes in power outage frequency	Medium
Electricity Demand							
Temperature	Increase in mean annual temperatures	Very Likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Increased energy demand	High	Increase in number of instances of peak load during summer, winter, and shoulder season	Medium
	Increase in extreme heat events; decrease in extreme cold events	Likely	N/A	Overwhelmed power supply system	Low	Increased frequency of blackouts and brownouts and reduced availability and reliability of power for downstate regions	High
Buildings							
Extreme events	Hurricanes and nor'easters	Uncertain	N/A	Heightened storm regime may reveal weaknesses in building envelopes	Medium	Increased chance of structural failure	Low
	Extreme wind events	Uncertain	N/A				
	Increased intense precipitation events	More likely than not	N/A	Low lying areas susceptible to more frequent flooding	High	Potential for structural damage to boilers	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, "Adaptation Guidebook")

Transportation

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Con-sequence*
Physical Assets							
Temperature	Increase in mean temperature	Very likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Freezing and thawing more common than steady below-freezing temperatures	Medium	Increased strain on road surface materials and potential for cracks and potholes in roads	Low
				Increased strain on A/C capacity	Medium	Increased strain on electricity grid	Medium
				Increased strain on runway material	Low	More frequent flight delays or cancellations	Medium
				Rail buckling	High	Delays in railroad schedules	Medium
				Increased strain on bridge materials	High	Sagging of large bridges	High
Precipitation	Increase in mean precipitation	More likely than not	N/A	Increased street flooding	Medium	Traffic delays	Low
						Delays in public transportation systems	Medium
	Amplified stream flow	More likely than not	N/A	Increased scour potential for bridge foundations	Medium	Reduced lifespan of current structures, potential need for new regulations	High
				Damage to road and rail embankments	Medium	Increased traffic and public transportation delays and rerouting	Medium
	Mudslides and landslides	Uncertain	N/A	Road and rail closures	Medium	Increased traffic and public transportation delays and rerouting, potential threat to lives	High
Temperature/ precipitation	Increase in droughts	Uncertain	Towards the end of the century, warm season droughts will more likely than not increase	Lower water level of lakes and canals due to higher rates of evaporation	Medium	Reduction in shipping capacity and increased costs of shipping due to required additional trips	Medium
Sea level rise	Increased storm surge and coastal flooding	Likely/very likely	Will depend both on sea level rise and on uncertain changes in tropical cyclones and nor'easters	Clearances of some bridges across waterways diminished below the limits set by the U.S. Coast Guard or other jurisdictions	High	Closure of bridges	High
				Flooding of bridge access ramps, tunnel entrances and ventilation shafts, and general highway beds	High	Traffic delays due to inundation	Low
				Reduced effectiveness of collision fenders on bridge foundations	High	Increase in impacts of ships or barges	Medium
				Flooding of roadways, railways, fuel storage farms and terminals, or maintenance facilities	Medium	Potential for equipment failure	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, “Adaptation Guidebook”)

Telecommunications

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Transmission and Distribution Assets							
Temperature	Increase in extreme heat events	Likely	N/A	Increase energy demand causing power failures	High	Reduction in telephone and cable services	High
Sea level rise	Increased frequency, intensity, and duration of storm surge and coastal flooding	Likely/very likely	Will depend on both sea level rise and on uncertain changes in tropical cyclones and nor'easters	Flooded central offices and underground installations	Medium	Reduced service	Medium
Extreme events	Extreme wind events	Uncertain	N/A	Fallen trees and downed wires	Low	Increased disruption of telephone and video service	Medium
	Snow storms	Uncertain	N/A	Strain on trees and utility lines from wet snow	Low	Reduction and delays in wired and cellular telephone service, as well as cable services	Medium
	Hurricanes	Uncertain	N/A	Power failures caused by high winds and storm surge	Medium	Increased strain on rerouting abilities of emergency calling centers	High
	Ice storms	Uncertain	N/A	Damage to utility lines and electrical equipment	Medium	Increased emergency communications and reduction in cable-provided services	High

Notes: N/A = Not Applicable
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, "Adaptation Guidebook")

Public Health

Main Climate Variable	Specific Climate Variable	Probability of Specific Climate Variable	Climate Variable Notes	Impact on Resource	Likelihood of Impact	Consequence without Adaptation	Magnitude of Consequence*
Air Quality							
Temperature	Increase in mean temperature	Very likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Extension of pollen and mold seasons	High	Asthma, which exhibits strong seasonal patterns related to pollen and mold seasons, is exacerbated	High
				Dust mites and cockroaches thrive at high temperatures and especially high absolute air humidity, which they depend upon for hydration	High	Asthma exacerbations triggered by greater presence of indoor allergens	High
				Increase in emission of volatile organic compounds	Medium	Increase in the amount of ozone being ingested results in short-term, reversible decreases in lung function and inflammation in the deep lung; also, epidemiology studies of people living in polluted areas have suggested that ozone can increase the risk of asthma-related hospital visits, and premature mortality	High
	Increase in extreme heat events	Likely	N/A	Peak in air conditioning use	High	Greater amount of emissions and resulting pollution from power plants	Medium
				Loss of on-site electricity	Low	Increase CO poisoning as a result of non-evacuated residents without back-up power	High
Precip-itation	Increase in mean precipitation	More likely than not	N/A	Weather patterns influence the movement and dispersion of all pollutants in the atmosphere	Medium	Potential increase in severe ozone episodes	High
Disease/Contamination							
Temperature	Increase in mean temperature	Very likely	Warming may be greater 1) in the north than south, and 2) in winter than in summer in the north	Increased population density and increase in biting rates of mosquitoes and ticks	Medium	Increase in infectious diseases spread by contaminated foods and water as well as those transmitted by insects	Medium
				Greater rates of overwinter survival of immature mosquitoes	High	Greater abundance of adults the following year that could potentially spread WNv	Medium
Precipitation	Increase in mean precipitation	More likely than not	N/A	Increased runoff from brownfields and industrial contaminated sites	Medium	Increased exposure to toxins creates health problems in respiratory and gastrointestinal tracts	High
				Receding floodwaters release molds and fungi that proliferate and release spores	High	Inhaled spores can cause respiratory irritation and allergic sensitization	High
Sea level rise	Increased storm surge and coastal flooding	Likely/Very likely	Will depend both on sea level rise and uncertain changes in tropical cyclones and nor'easters	Greater frequency of flooding events	High	Greater potential for drowning, delayed health service delivery	High
Mental Health							
Sea level rise	Increased storm surge and coastal flooding	Likely/Very likely	Will depend both on sea level rise and uncertain changes in tropical cyclones and nor'easters	Increased property damage (e.g., loss), displacement/family separation, violence, stress effects	High	Increase in anxiety, depression, PTSD as a result of low resilience capacity, lack of access to evac transportation, low SES	High

Notes: N/A = Not Applicable
CO = Carbon Monoxide
PTSD = Post traumatic stress disorder
* Factors that are considered when determining the magnitude of consequence, defined as the combined impact of the occurrence should a given hazard occur, include: effects on internal operations, capital and operating costs, public health, the economy, and the environment, as well as the number of people affected. (see Annex II to the full report, "Adaptation Guidebook")

Adaptation

New York State has significant resources and capacity for effective adaptation responses, which are characterized by a wide range of types, actors, levels of effort, timing, and scales (**Table 12.3**). A critical resource for the state are the existing codes, standards, and regulations that could be enhanced in a comprehensive adaptation approach. Developing climate change adaptation plans requires input from a breadth of academic disciplines as well as stakeholder experience to ensure that recommendations are both scientifically valid and practically sound (see Annex II to the full report).

Identifying the co-benefits of adaptation strategies is important, since they are positive effects that adaptation actions can have on mitigating climate change (i.e., reduction of greenhouse gas emissions) or on improving other aspects of the lives of New York State citizens. An example of a mitigation co-benefit is the establishment of green roofs that keep residents cooler while reducing the use of air conditioners, thereby reducing fossil fuel emissions at power plants. An example of a co-benefit with other aspects is the upgrading of combined sewer and stormwater systems to reduce current water pollution, while helping to prepare for future climate change impacts.

Some adaptation options may either complement or negatively affect mitigation efforts to reduce greenhouse gas emissions. For example, avoiding adverse public health impacts related to heat waves may result in increased reliance on air conditioning. This could counteract mitigation options designed to reduce energy consumption and could potentially result in increased energy demand during summer peak-load conditions.

Key Sector Adaptations

Potential adaptation strategies for the identified climate vulnerabilities are summarized in **Table 12.4**. These are to be considered as options for adaptive measures and should not be considered as an exhaustive list. For each sector, selected adaptation strategies that respond to key climate risks are presented in terms of short-, medium-, and long-term time scales and by operations/management, capital investment, and policy categories. The three categories are presented as a way of illustrating the varying range and focus of potential adaptation strategies. It is recognized that in many cases there will be significant overlap among the categories when the strategies are operationalized.

The key adaptations are broken into time groups: 0 to 10 years (i.e., to 2020), 10 to 40 years (i.e., to 2050), and more than 40 years (i.e., beyond 2050) (see **Table 12.4**). The short-term adaptations that are identified in the tables will often be continued into the medium and long terms, but to facilitate a focused overview, they are not necessarily repeated in each column of the table. Thus, while a short-term operations/management strategy—one involving small adjustments to everyday practices—will probably be continued throughout the longer period, it is listed as short-term to indicate its earliest use/implementation. "Ongoing" refers to work that is taking place at present and expected to continue over time.

Adaptation Mechanism	Definitions
Type	Behavior, management/operations, infrastructure/physical components, risk-sharing, and policy (including institutional and legal)
Administrative group	Private vs. public; governance scale – local/municipal, county, state, national
Level of effort	Incremental action, paradigm shift
Timing	Years to implementation, speed of implementation (near-term/long-term)
Scale	Widespread, clustered, isolated/unique

Table 12.3 Adaptation categories

Table 12.4 Selected Adaptation Strategies by Sector

Selected adaptation strategies by sector responding to key climate risks	Type*	Timing**
Water Resources		
Build on the existing capacity of water managers to handle large variability	O/M	O
Expand basin-level commissions to provide better oversight of water supplies in systems with multiple users, address water quality issues, and take leadership on basin-level monitoring, conservation, and coordination of emergency response	CI, P	S
Update and enlarge stockpiles of emergency equipment, including mobile pumps, water tanks, and filters, to help small water supply systems and to assist during emergencies	CI	S
Establish streamflow regulations that mimic natural seasonal flow requirements to protect aquatic and ecosystem health	O/M, P	S
Increase water use efficiency through leak detection programs, low-flow devices, rainwater harvesting, and equitable water-pricing programs	O/M, P	S
Develop more comprehensive drought management programs that include improved monitoring of water supply storage levels and that institute specific conservation measures when supplies decline below set thresholds	O/M, P	S to M
Explore new economic opportunities for New York State's relative wealth of water resources	P	M
Upgrade combined sewer and stormwater systems to reduce pollution and mitigate climate change impacts	CI	M
Adopt stormwater management infrastructure and practices to reduce the rapid release of stormwater to water bodies	O/M, P	M to L
Relocate and rebuild aging infrastructure out of high-risk flood-prone areas; construct levees and berms where necessary to remain in the flood plain	CI	L
Coastal Zones		
Site new developments outside of future floodplains, taking into consideration the effects of sea level rise, barrier island and coastline erosion, and wetland inundation	P	O
Improve building codes to promote storm-resistant structures and increase shoreline setbacks	O/M, P	S
Use rolling easements to protect coastal wetlands (recognize nature's right-of-way to advance inland as sea level rises)	P	M
Use engineering-based and bio-engineered strategies to protect coastal communities from floods or to restore wetlands	O/M	M
Maintain and expand beach renourishment and wetland restoration programs	O/M, P	M
Relocate coastal infrastructure and small, rural developments to higher elevations	CI, P	L
Buy out land or perform land swaps to encourage people to move out of flood-prone areas	CI, P	L
Ecosystems		
Minimize stressors such as pollution, invasive species, sprawl, and other habitat-destroying forces	O/M	O
Develop reliable indicators of climate change impacts on biodiversity and ecosystem services, and cost-effective strategies for assessing climate change impacts	O/M	O
Manage primarily for important ecosystem services and biodiversity rather than attempting to maintain the current mix of species present today	O/M	O
Facilitate natural adaptation to climate change by protecting stream (riparian) zones and migration corridors for species adjusting to changes in the climate	O/M, P	S
Institutionalize a comprehensive monitoring effort to track species range shifts and to track indicators of ecosystem response to climate change	O/M, P	M
Develop cost-effective management interventions to reduce vulnerability of high-priority species and communities, and determine minimum area needed to maintain boreal or other threatened ecosystems	O/M, P	M
Agriculture		
Change planting dates, varieties, or crops grown; increase farm diversification	O/M	S
Develop strategic adaptation decision tools to assist farmers in determining the optimum timing and magnitude of investments to cope with climate change	CI, P	S
Increase control of pests, pathogens, and weeds and use of new approaches to minimize chemical inputs	O/M	S
Improve cooling capacity and use of fans and sprinklers in dairy barns	CI	M
Invest in irrigation and/or drainage systems	CI	M
Develop new crop varieties for projected New York State climate and market opportunities	CI	M
Build supplemental irrigation with good drainage capacity for high-value crops	CI	M

Note: The key adaptations are broken into time groups: 0 to 10 years (i.e., to 2020), 10 to 40 years (i.e., to 2050), and more than 40 years (i.e., beyond 2050). The short-term adaptations that are identified will often be continued into the medium and long terms, but to facilitate a focused overview, they are not necessarily repeated in each column of the table. Thus, while a short-term operations/management strategy—one involving small adjustments to everyday practices—will probably be continued throughout the longer period, it is listed as short term to indicate its earliest use/implementation.

* O/M = Operations/Management, CI = Capital Investment, P = Policy,

** S = Short-term, M = Medium-term, L = Long-term, 0 = Ongoing

Selected adaptation strategies by sector responding to key climate risks	Type*	Timing**
Energy		
Balance the need to make energy systems more resilient with the cost of such investments and changes	O/M	O
Improve system resiliency with the replacement cycle of energy system assets	CI	O
Use transformers and wiring that function efficiently at higher temperatures	CI	S
Maintain and expand tree trimming programs next to power lines	O/M	S
Adjust reservoir release policies to ensure sufficient summer hydropower capacity	O/M	S
Prioritize demand-side management, which encourages consumers to use energy more efficiently	P	S
Shade buildings and windows or use highly reflective roof paints and surfaces to reduce warming in buildings from sun exposure	O/M	S
Improve energy efficiency in areas likely to have the largest increases in demand, to reduce strain on electrical equipment during heat waves	O/M, P	S
Construct berms and levees to protect infrastructure from flooding; install saltwater-resistant transformers to protect against sea level rise and saltwater intrusion	CI	M to L
Transportation		
Adopt operational measures to cope with high wind speeds, such as allowing bridge traffic only at reduced speeds or, for higher wind speeds, suspending traffic	O/M, P	S
Form alliances among agencies to set performance standards and work together to reduce risks, such as through mutual insurance pools that spread risks across time, space, and type	O/M	S
Perform engineering-based risk assessments of assets and operations and complete adaptation plans based on these assessments	CI, P	S to M
Relocate critical systems to higher ground out of future flood zones	CI	M
Create strategies to protect against heat hazards, including increasing the seat length of expansion joints on bridges, lengthening airport runways, and increasing and upgrading air conditioning on trains, subways, and buses	CI	M to L
Devise engineering-based solutions to protect against coastal hazards, including constructing levees, sea walls, and pumping facilities; elevating infrastructure, including bridge landings, roads, railroads, and collision fenders on bridge foundations; and designing innovative gates at subway, rail, and road entrances	CI	M to L
Develop engineering-based solutions to protect against heavy-precipitation hazards, including increasing the capacity of culverts and other drainage systems; raising and/or strengthening road and rail embankments to make them more resistant to flood-related erosion and river scour; and creating more permeable surfaces or regrading slopes to direct runoff away from critical transportation infrastructure	CI	L
Telecommunications		
Reassess industry performance standards combined with more uniform regulation across all types of communication services; provide better enforcement of regulations, including uniform mandatory reporting of outages to regulatory agencies	O/M, P	S
Further develop backup cell phone charging options, such as car chargers, and create a charging interface that allows any phone to be recharged by any charger	CI	S
Develop high-speed broadband and wireless services in low-density rural areas to increase redundancy and diversity in vulnerable remote regions	CI	S
Trim trees near power and communication lines, maintain backup supplies of poles and wires to replace those that are damaged, and have emergency restoration crews at the ready to protect against outages	O/M	S, O
Assess, develop, and expand alternative communication technologies with the goal of increasing redundancy and/or reliability, including free-space optics (which transmits data with light rather than physical connections), power line communications (which transmits data over electric power lines), satellite phones, and ham radio	CI	M
Place communication cables underground where technically and economically feasible	CI	M
Decouple communication facilities from electric grid infrastructure to the extent possible, and/or make these infrastructures more robust, resilient, and redundant	CI	M
Minimize the effects of power outages on communications services by providing backup power at cell towers, such as with generators, solar-powered battery banks, and "cells on wheels" that can replace disabled towers; extend the fuel storage capacity needed to run backup generators for extended times	CI	M
Relocate central offices that house communications infrastructure out of future floodplains	CI, P	L
Public Health		
Integrate adaptation strategies into existing surveillance, prevention, and response programs	O/M	S
Better coordinate environment and health initiatives so they address both human health and ecosystem health and avoid the legislative divide that often exists between them	O/M, P	S
Increase use of air conditioning during heat waves for vulnerable individuals, but use alternative energy sources to avoid increased greenhouse gas emissions	O/M	S
Provide alerts regarding potential health risks, such as those from extreme heat events, which convey information and needed actions to vulnerable communities	O/M, P	S
Implement extreme-heat response plans, such as longer opening hours for air-conditioned community centers for seniors, reduced fares on public transportation, and neighborhood buddy systems to check on those most vulnerable	O/M, P	S
Plant low-pollen trees in cities to reduce urban heat without increasing allergenic pollen	CI	M
Invest in structural adaptations to reduce heat vulnerability, including tree planting, green roofs, and high-reflectivity building materials	CI	M to L

Note: See previous page

Equity and Environmental Justice

Certain groups, types of communities, and regions within the state are better able to respond to climate risk and vulnerabilities than others. Communities, groups, and locations currently at risk because of limited response capacity and resilience to climate hazards (e.g., those who are economically marginal) are, in most cases, those that will be most vulnerable to future climate change impacts. Such groups include the elderly and disabled, as well as people with low incomes and the underprivileged.

Elderly and health-compromised individuals are more vulnerable to climate hazards, including floods and heat waves. Low-income groups have limited ability to meet higher energy costs, making them more vulnerable to the effects of heat waves. Those who lack affordable healthcare are more vulnerable to climate-related illnesses such as asthma. Those who depend on public transportation to get to work, and lack private cars for evacuating during emergencies, are also vulnerable. Farm workers may be exposed to more chemicals if pesticide use increases in response to higher pest infestations brought about by a warming climate.

It is not clear at this time how the costs of adaptation will be distributed. In general, groups with more limited means to respond to increased risks or to provide funds for adaptation, such as smaller businesses, may be less able to cope. This condition extends across both the public and the private sectors.

Economics

The costs of climate change impacts will vary across and within sectors (see Annex III to the full report). Overall costs of impacts within the energy, transportation, and coastal zone sectors will be most significant, likely by many-fold, but impacts within each sector will be significant depending on the structure of that sector. This is well illustrated in the agriculture and ecosystem sectors, where particular components such as specific crops and modes of production or rare and endangered ecosystems and species could be significantly affected by climate change in comparison to other parts of the sectors.

There are several types of costs associated with climate impacts and adaptation. Direct costs include costs that are incurred as the direct economic outcomes of a specific climate event or aspect of climate change. Indirect costs are those incurred as secondary outcomes of the direct costs of a specific event or facet of climate change. Impact costs are direct costs associated with the impacts of climate change, and adaptation costs include the direct costs associated with adapting to those impacts. The direct costs of impacts that cannot be adapted to are the costs of residual damage.

The costs of adapting to climate change are already occurring and will grow over time. Adaptation response costs and benefits will not be evenly distributed throughout the state. For example, a significant amount of the benefits of adaptation to sea level rise will be experienced only by communities and property owners in the coastal zone.

Recommendations

This section presents recommendations for policy and management that arise from the ClimAID Assessment. Policy recommendations are aimed at statewide decision-makers, and management recommendations are associated with everyday operations within stakeholder agencies and organizations, as they respond to the challenge of climate change. Sector-specific knowledge gaps and information needs are identified, as well as recommended directions for further science and research activities.

Policy

Key policy recommendations, targeted for New York State decision-makers, are discussed in this section.

- Promote adaptation strategies that enable incremental and flexible adaptations within sectors, among communities, and across time.
- Analyze environmental justice issues related to climate change and adaptation on a regular basis.
- Evaluate design standards and policy regulations based on up-to-date climate projections.
- Consider regional, federal, and international climate-related approaches when exploring climate adaptation options. This is crucial because it is clear that New York State's adaptation potential (and

mitigation potential as well) will be affected by national and international policies and regulations as well as state-level policies.

- Improve public and private stakeholder and general public education and awareness about all aspects of climate change. This could encourage the formation of new partnerships for developing climate change adaptations, especially given limited financial and human resources, and the advantages of shared knowledge.
- Identify synergies between mitigation and adaptation. Taking steps to mitigate climate change now will help to reduce hazards and enhance opportunities for co-benefits. Conversely, many potential adaptation strategies present significant mitigation opportunities.
- Develop standardized, statewide climate change mitigation and adaptation tools, including a central database of climate risk and adaptation information resulting from ongoing partnerships between scientists and stakeholders.

Management

Management recommendations associated with everyday operations in stakeholder agencies and organizations are described here.

- Integrate climate adaptation responses into the everyday practices of organizations and agencies, with the potential for synergistic or unintended consequences of adaptation strategies taken into account.
- Take climate change into account in planning and development efforts.
- Identify opportunities for climate adaptation partnerships among organizations and agencies.

Knowledge Gaps and Information Needs

There has been great advancement in knowledge surrounding climate change, impacts, and adaptation over the past few decades. However, there are still areas where further research would complement and further the understanding, help to reduce uncertainties, and aid in better decision-making. Key areas of knowledge gaps and information needs for each sector are outlined in **Table 12.5**.

Table 12.5 Knowledge Gaps and Information Needs by Sector

Sector-specific and statewide knowledge gaps and information needs	Type (Climate science, impact, adaptation)
Water Resources	
Identification of critical pollutant-contributing areas and processes	Impact
More in-depth assessment of how fundamental hydrologic processes, such as groundwater recharge, stream low-flows, evaporation, and flooding, might be altered by a changing climate	Impact
Refinement of existing monitoring networks	Climate science
Updated estimates of streamflow and water temperature scenarios based on future climate changes	Climate science
Models of the impacts on the quality of water bodies receiving effluent	Impact
Coastal Zones	
Research on the response of barrier islands to accelerated rates of sea level rise	Climate science
Improved understanding of regional sediment transport processes along the coast and continental shelf	Climate science
Quantified and monitored land use and coastal water quality	Impact
Assessment of ecosystem services for natural and engineered shorelines	Impact
Monitoring program for submarine groundwater discharge	Impact
Systematic mapping (every two to five years) and standardized mapping protocols for all New York State coastal regions	Climate science
GIS-based data repository to facilitate interagency collaboration and future assessments	Impact
Improved hydrodynamic modeling capability for the Hudson River	Climate science
Ecosystems	
Reliable indicators of climate change impacts on biodiversity and ecosystem functions, and cost-effective strategies for monitoring these impacts	Climate science/impact
Cost-effective management interventions to reduce vulnerability of high-priority species and communities, and determination of the minimum area needed to maintain boreal and other threatened ecosystems.	Impact
Evaluation techniques for rapid and reliable assessment of vertebrate abundance at the landscape scale	Climate science
Improvements in techniques used to identify and target invasive species likely to benefit from climate change	Climate science
Development of citizen-science programs that can provide accurate and reliable data on change in species distributions and movements	Impact
Agriculture	
Non-chemical control strategies for weed and pest threats	Impact
New economic decision tools for farmers	Impact
Sophisticated real-time weather-based systems for monitoring and forecasting crop stress	Climate science
Crops with increased tolerance to climate stresses	Impact
Energy	
Review of thermoelectric power intake or discharge rules in light of a changing climate	Impact
Identification of temperature tipping points related to failure of the energy supply system	Impact
Potential impacts of climate change on wind patterns and speeds in selected areas currently used or proposed for wind farm development	Climate science/impact
Potential impacts of climate change on biomass-based heat production (either at a large central station or co-firing facilities)	Climate science/impact
Assessment of potential impacts of climate change on hydropower availability in different parts of the state	Climate science/impact
Evaluation of potential climate impacts on the demand for natural gas and other heating fuels given anticipated decreases in heating degree-days over the coming decades	Impact
Better understanding of the impact of extreme events on electricity demand	Climate science
Transportation	
Accurate, high-resolution LIDAR surveys to facilitate the development of digital elevation models (DEM) of sufficiently high vertical and horizontal resolution to perform forward-looking flood risk assessments and regional planning of sustainable developments	Impact
Development of updated climate information that includes climate change projections for standards and regulations	Climate science
Comprehensive program of research and technological development for advancing innovative, cost-effective, and climate-resilient urban and inter-urban transportation infrastructure	Impact
Telecommunications	
Creation of computerized (proprietary) databases that show the location and elevations of installed communication facilities and lifelines and their operational capacity and other details	Impact
Improved knowledge-sharing tools to disseminate information about service outages and expected restoration times to the public	Impact
Public Health	
Ongoing, state-based research to inform periodic policy developments, especially that which identifies cross-sectoral interactions and win-win options for adaptation/mitigation, including extensive health co-benefits assessments	Impact
Development and analysis of local health impact projections of climate factors and related disease outcomes	Impact
Information and capacity-building for integrating climate change into public health planning at all levels of government	Impact

Science and Research

This section presents recommendations for future science and research.

- Refine climate change scenarios for New York State on an ongoing basis, as results from new climate models and downscaled products become available.
- Conduct research on understanding climate variability, including stakeholder-identified variables, such as ice storms, extreme precipitation events, wind patterns, etc.
- Conduct targeted impacts research in conjunction with regional stakeholders.
- Implement and institutionalize an indicators and monitoring program focused on climate, impacts, and adaptation strategies.
- Improve spatial analysis and mapping to help present new data.
- Focus studies on specific systems that may enter into a phase change or similar shifts in process, known as "tipping points." Work should be encouraged to understand the potential for tipping points associated with climate change impacts on natural and social systems.
- Develop a better understanding of the economic costs of climate change and benefits of adaptations.

Responding to Future Climate Challenges

New York State is highly diverse, with simultaneous and intersecting challenges and opportunities presented by a changing climate. Among the people, sectors, and regions of the state, those that are already facing significant stress will likely be placed most at risk by the effects of future climate change. Responding to these challenges and opportunities will depend on how stakeholders develop effective adaptation strategies by connecting climate change with ongoing proactive management and policy initiatives within the state and beyond.

The adaptation strategies suggest several important perspectives: First, there is a wide range of adaptation needs across sectors. Second, there are many adaptation needs that can be undertaken or reviewed in the near term, in most cases at relatively modest cost. Third, there are some potential infrastructure investments—especially relating to the transportation sector and coastal zones—that could be needed in the long term and that may be expensive. These perspectives also suggest the need for increased interactions between scientists and policy-makers, and consideration of methods for ensuring that science better informs policy, as well as increased scientific and technical capabilities. The overall goal is the development of equitable and efficient climate resilience throughout New York State in the decades to come.

Annex I
Expert Reviewers for the ClimAID Assessment

Chapter	Reviewer	Affiliation
Introduction	Virginia Burkett	U.S. Geological Survey
	Paul Fleming	Seattle Public Utilities
Climate	David Yates	National Center for Atmospheric Research
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	Kathy Jacobs	White House Office of Science and Technology Policy
	Paul Fleming	Seattle Public Utilities
Vulnerability and Adaptation	Kirstin Dow	University of South Carolina
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	Stewart Cohen	Environment Canada / University of British Columbia
Equity and Economics	Rae Zimmerman	New York University
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	Karen O'Brien	University of Oslo
	Vicki Arroyo	Georgetown University
Water Resources	Doug Burns	U.S. Geological Survey, New York Water Science Center
	Brad Udall	University of Colorado
Coastal Zones	Robert Deyle	Florida State University
	Paul Kirshen	Battelle Duxbury MA
Ecosystems	Jerry Jenkins	Wildlife Conservation Society Forest Issues
	Gary Lovett	Cary Institute of Ecosystem Studies
	Nicholas Rodenhouse	Wellesley College
Agriculture	Greg Albrecht	NYS Department of Agriculture and Markets / Empire Soil and Water Conservation Society
	David Abler	Pennsylvania State University
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	Stanley Bull	National Renewable Energy Laboratory
	Vatsal Bhatt	Brookhaven National Laboratory
	Matthias Ruth	University of Maryland
Transportation	Mark Horner	Florida State University
	Michael J. Savonis	U.S. Department of Transportation
Telecommunications	Mike Hainzl	Ericsson Inc.
	Craig Faris	Accenture
Public Health	Christine Rogers	University of Massachusetts, Amherst
	Paul Epstein	Harvard Medical School Center for Health and the Global Environment

ClimAID Annex II

Climate Adaptation Guidebook for New York State

Authors: Cynthia Rosenzweig, Arthur DeGaetano, William Solecki,Radley Horton, Megan O'Grady, Daniel Bader

New York State Energy Research and Development Authority

Climate Adaptation Guidebook for New York State

NYSERDA
November 2011

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Climate Adaptation Guidebook for New York State

Annex II to the ClimAID Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State

Authors: Cynthia Rosenzweig, Arthur DeGaetano, William Solecki, Radley Horton, Megan O'Grady, Daniel Bader

NYSERDA
November 2011

Responding to Climate Change in New York State

Climate change is already beginning to affect the people and resources of New York State, and these impacts are projected to grow. At the same time, the state has the potential capacity to address many climate-related risks, thereby reducing negative impacts and taking advantage of possible opportunities.

ClimAID: The Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State was undertaken to provide decision-makers with cutting-edge information on the state's vulnerability to climate change and to facilitate the development of adaptation strategies informed by both local experience and scientific knowledge.

This state-level assessment of climate change impacts is specifically geared to assist in the development of adaptation strategies. It acknowledges the need to plan for and adapt to climate change impacts in a range of sectors: Water Resources, Coastal Zones, Ecosystems, Agriculture, Energy, Transportation, Telecommunications, and Public Health.

The author team for the report is composed of university and research scientists who are specialists in climate change science, impacts, and adaptation. To ensure that the information provided would be relevant to decisions made by public and private sector practitioners, stakeholders from state and local agencies, non-profit organizations, and the business community participated in the process as well.

This Guidebook will help develop climate change adaptation strategies using a risk management approach. The larger technical report provides useful information to decision-makers, such as state officials, city planners, water and energy managers, farmers, business owners, and others as they begin responding to climate change in New York State.

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Rosenzweig, Cynthia, Arthur DeGaetano, William Solecki, Radley Horton, Megan O'Grady, Daniel Bader. 2011. ClimAID Adaptation Guidebook for New York State. Annex II of *Responding* to *Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State*. New York State Energy Research and Development Authority (NYSERDA). Albany, NY.

I. Climate Change and New York State

Over the last century, global mean temperatures and sea levels have been increasing and the Earth's climate has been changing. As these trends continue, climate change is increasingly being recognized as a major global concern. In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) formed an international panel of leading climate scientists, coined the Intergovernmental Panel on Climate Change (IPCC), to provide objective and up-to-date information regarding the changing climate. In its 2007 Fourth Assessment Report (AR4), the IPCC states that there is a greater than 90 percent chance that rising global temperatures, as observed since 1750, are primarily the result of human activities.

As predicted in the 19th century, the principal driver of climate change over the past century has been the increase in levels of atmospheric greenhouse gases (GHGs) associated with fossil-fuel combustion, changing land-use practices, and other human activities. The atmospheric concentrations of the major GHG carbon dioxide (CO_2) are now more than one-third higher than in pre-industrial times. The concentrations of other important GHGs, including methane (CH_4), ozone (O_3), and nitrous oxide (N_2O), have increased as well. Largely resulting from work performed by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC), global efforts to mitigate the severity of climate change by limiting levels of GHG emissions are now underway.

Because some of the added GHGs will remain in the atmosphere for centuries, and some parts of the climate system respond in a gradual manner, awareness is growing that some climate changes are inevitable. Responses to climate change have evolved from focusing on *mitigating* or reducing the amount of GHGs released into the atmosphere to including *adaptation* measures in an effort to both minimize the impacts and prepare for unavoidable future changes. In some cases, climate change may bring opportunities. (For more information, see the full ClimAID Technical Report.)

New York State possesses a wide range of vulnerabilities to a changing climate and, at the same time, has great potential to adapt to its impacts. From the Great Lakes to Long Island Sound, from the Adirondacks to the Susquehanna Valley, climate change will affect the people and resources of New York State. Risks associated with climate change include higher temperatures leading to greater incidence of heat stress caused by more frequent and intense heat waves; increased summer droughts and extreme rainfall affecting food production, natural ecosystems, and water resources; and sea level rise causing exacerbated flooding in coastal areas.

Climate change—and associated uncertainties in future climate projections, as well as complex linkages among climate change, physical systems, biological systems, and socioeconomic factors—poses special challenges for New York State decision-makers. However, there is a knowledge base that decision-makers can use to make progress in reducing vulnerability to climate change and building adaptive capacity needed to respond to extremes in the current climate, as well as increased climate risks in the future.

This *Climate Adaptation Guidebook for New York State* describes a risk management approach to developing climate change adaptation strategies. The climate change adaptation process involves understanding climate trends and projections, identifying vulnerabilities, assessing the risk levels, and developing and prioritizing strategies. The guidebook discusses these key aspects in the context of New York State. By developing climate change adaptation strategies following a risk management approach, New York State can effectively respond to future climate impacts.

Key Definitions for Responding to Climate Change

Adaptation – Actions that take place in response to a changing climate. Actions can create opportunities or challenges.

Adaptive capacity – Ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences.

Adaptation strategies – Operational, managerial, budgetary, or infrastructure changes that will result in reducing risk and/or taking advantage of potential opportunities associated with climate change. A strategy is usually developed for a key vulnerability. Adaptation strategies do not directly include actions that reduce the likelihood of climate change occurring.

Climate resilience – A state in which climate risk information, vulnerability, and adaptation knowledge are taken into account in order to reduce the level of physical, social, or economic impact of climate variability and change.

Climate risks – Generally, risk is a product of the likelihood of an event occurring (typically expressed as a probability) and the magnitude of consequences should that event occur. For climate change impacts, risk can be thought to have three dimensions: the probability of a climate hazard occurring; the likelihood of impacts associated with that hazard; and the magnitude of consequence, should that impact occur. These risk estimates can be adapted and improved as additional information becomes available.

Impacts – The natural or potential effects a change in climate has or could have on natural or human systems.

Mitigation – Direct actions that reduce the concentrations of greenhouse gases in the atmosphere and other factors that are currently altering, or have the potential to alter, the earth's climate system.

Prioritization – Methods to assess and evaluate a set of adaptation strategies to determine those that are more pressing or suitable to undertake. Various prioritization criteria can be used.

Vulnerability – The degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change.

Sources: IPCC (2007) and New York City Panel on Climate Change (NPCC) (2010)

II. Framing Adaptation

Developing climate change adaptation involves understanding how the *climate* in New York State might change; identifying potential *vulnerabilities* a change in climate might create; assessing *risk* levels of those vulnerabilities; developing *adaptation strategies* that will help to minimize those risks; and prioritizing those strategies. This process helps to distill the complexities involved in considering climate change, its impacts, and how to adapt. The outcome of the process involves enhancing the overall *adaptive capacity* of a particular region, jurisdiction, or organization. *Adaptive capacity* is defined as the ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences (see Figure 1).

Risk Management

Climate adaptation strategies and actions have a direct connection to risk and hazards management. Individuals and organizations reduce their vulnerability and exposure to threats through risk management as they develop protocols to avert and manage hazards and promote disaster risk reduction, especially around areas of uncertainty. Stakeholders can modify risk management tools, such as a risk matrix, for climate change adaptation, especially as a way to deal with the uncertainties surrounding climate hazards and associated impacts. Other uncertainties that may affect climate change adaptation include changes in technologies and social dynamics. The exact need and context in which stakeholders develop adaptation strategies reflect both the history and emerging understanding of the amount and significance of ongoing climate change.

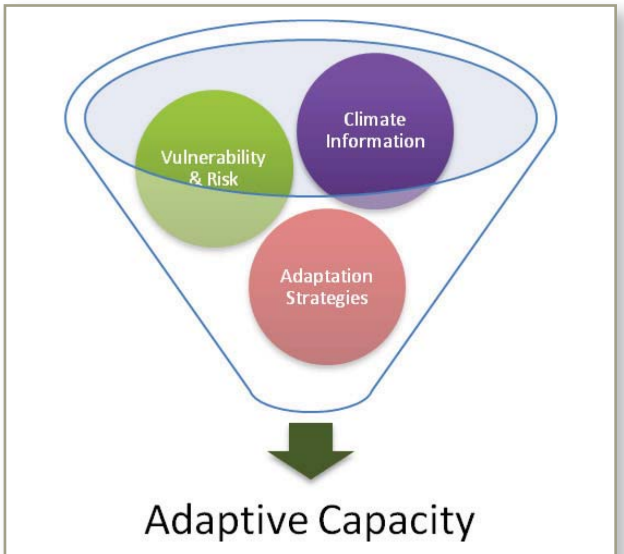


Figure 1. Climate Change Adaptive Capacity

Climate Resilience and Flexible Adaptation Pathways

To build climate resilience, climate change adaptation should allow for flexible responses to changing climate conditions. Flexible adaptation consists of implementing actions or infrastructure that stakeholders can adjust or shift over time in response to new climate science and evidence from ongoing monitoring, as well as implementing shifts in policies and strategies to better respond to emerging climate threats and opportunities (see Figure 2).

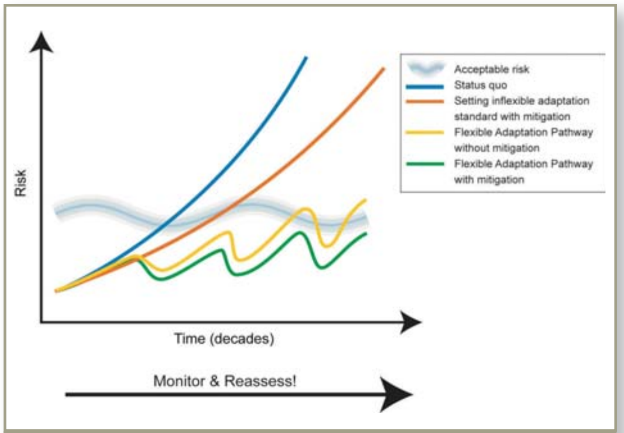


Figure 2. Flexible Adaptation and Mitigation Pathways

Graphic adapted from Lowe (2009)

An acceptable level of risk, as determined by society, is likely to change over time; for instance, the acceptable level of risk is likely to be lower after an extreme event, such as a hurricane. A one-time static or inflexible adaptation is better than maintaining the status quo, but such actions would still eventually result in crossing into an unacceptable level of risk, when climate conditions change beyond what the action was designed to withstand. *Flexible adaptation pathways* that include both adaptation and mitigation allow policymakers, stakeholders, and experts to develop and implement strategies that evolve as climate change progresses. The process of adaptation assessment can be summarized in an eight-step process (see Section IV) and adjusted as needed, depending on varying circumstances.

III. Current Climate and Climate Change Projections

This section provides an overview of the current climate in New York State and summarizes the climate change projections for New York. Understanding the climate is the first step in developing adaptation strategies for New York State (see Section IV).

New York State's Climate

The following components are key features of New York State's climate:

- Average annual temperature varies from 40°F in the Adirondacks to near 55°F in the New York City metropolitan region.
- Average annual precipitation ranges from approximately 30 inches in Western New York to close to 50 inches in the New York City region, Tug Hill Plateau, and Adirondacks.
- The state experiences a variety of extreme events:
  - **Heat waves** are common in urban areas, especially in the southern parts of the state.
  - **Short-duration flooding,** which can result from heavy rainfall and/or runoff from snowmelt, affects the entire state.
  - **Lake-effect snow** is a major climate hazard in western and central New York State.
  - **Coastal storms** along the Atlantic coast and Hudson River Valley bring heavy precipitation, high winds, and flooding.

Because New York State's climate is varied, climate impacts and effective adaptation strategies will be varied as well.

New York State Climate Regions

The climate of New York State varies from the Great Lakes to Long Island Sound. To help in developing adaptation strategies, the ClimAID assessment divided New York State into seven regions, as shown in Figure 3.

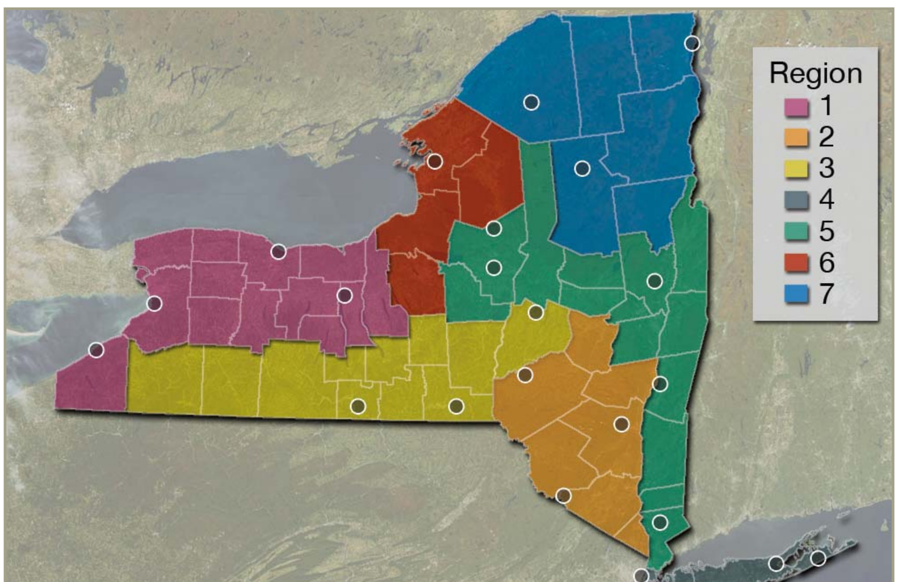


Figure 3. ClimAID Regions

Observed Climate Trends

Temperatures in New York State have risen over the course of the 20th century, with the greatest warming occurring in recent decades. New York State has experienced an increase in extreme hot days (days at or above 90°F) and a decrease in cold days (days at or below 32°F). In addition, the sea level has steadily risen in the coastal areas of the state. Figure 4 shows observed 20th century trends in temperature, precipitation, and sea level rise for New York City (ClimAID Region 4); these trends serve as an example of how the climate has already begun to change in different parts of the state.

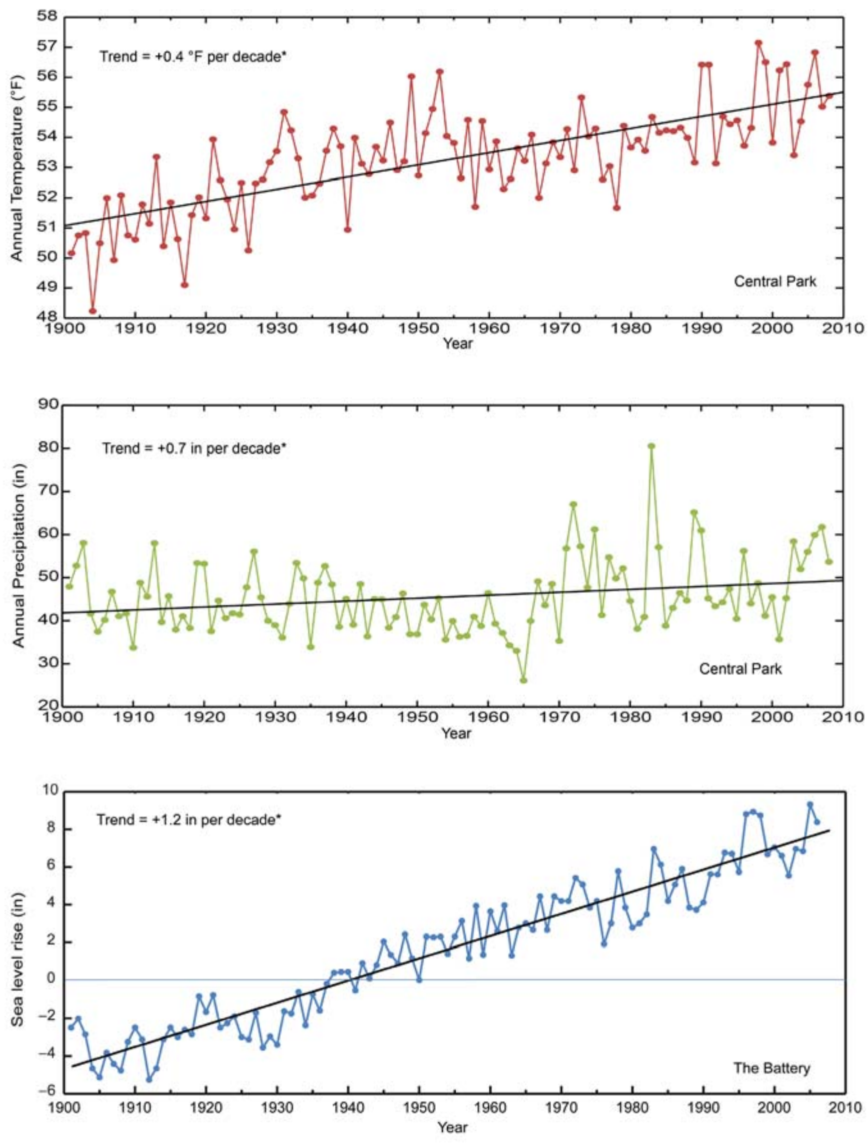


Figure 4. Observed Annual Temperature, Precipitation, and Sea Level Rise Over the 20th Century for New York City (ClimAID Region 4)

***All trends significant at the 1 percent level.**

Future Projections

To produce future climate scenarios, experts use global climate models with a number of possible GHG emissions scenarios. Each emissions scenario represents a set of different demographic, social, economic, technological, and environmental assumptions about the future, called "storylines" (IPCC, 2000). The ClimAID team used three GHG emissions scenarios, as shown in Figure 5. The three scenarios and the storylines the team used in the ClimAID Assessment are described in Table 1.

Scenario	Storyline
A2	Relatively rapid population growth and limited sharing of technological change combine to produce high GHG levels by the end of the 21st century, with emissions growing throughout the entire century.
A1B	Effects of economic growth are partially offset by the introduction of new technologies and decreases in global population after 2050. This trajectory is associated with relatively rapid increases in GHG emissions and the highest overall CO2 levels for the first half of the 21st century, followed by a gradual decrease in emissions after 2050.
B1	This scenario combines the A1/A1B population trajectory with societal changes tending to reduce GHG emissions growth. The net result is the lowest GHG emissions of the three scenarios, with emissions starting to decrease by 2040.

Table 1. Greenhouse Gas Emissions Scenarios and Storylines

Other emissions scenarios yield different GHG concentrations by the end of the 21st century as compared to the three scenarios ClimAID used. The IPCC's "A1FI" scenario, for example, projects even higher CO_2 concentrations than those shown in Figure 5. The A1FI scenario was not included, however, because very few global climate model results are available for the scenario. However, experts should continue to reassess high-end climate change scenarios such as this over time.

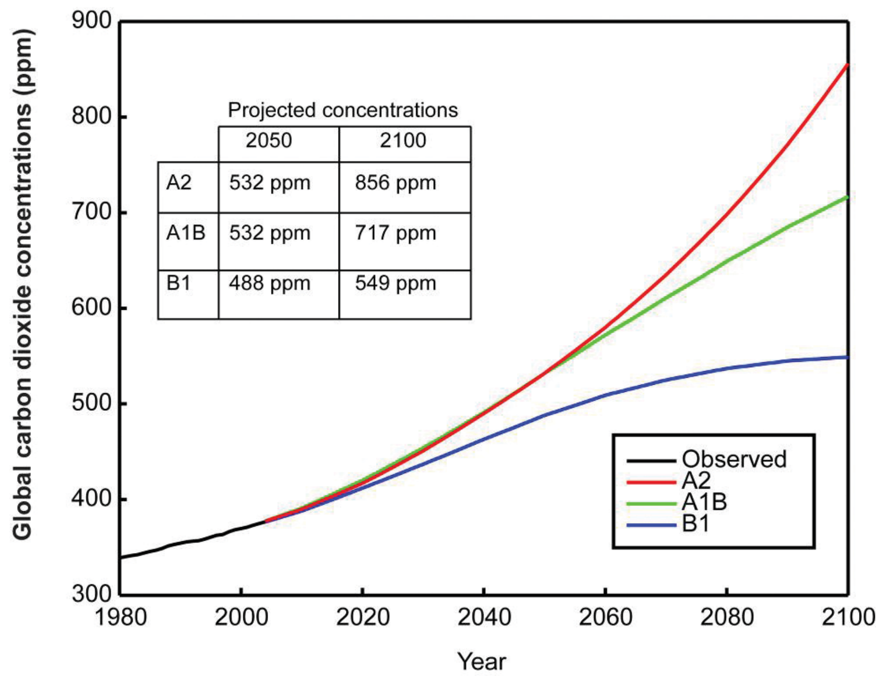


Figure 5. Observed Carbon Dioxide Concentrations Through 2003 and Future Carbon Dioxide Concentrations in the A2, A1B, and B1 Scenarios (2004–2100)

Source: IPCC (2000)

The ClimAID team divided the projections produced from the global climate models into two categories: mean annual changes and changes in extreme events. For the ClimAID Assessment, the team produced projections for each of the seven regions shown in Figure 3. The sections below present projections for a few of the regions, as examples. For the full suite of the ClimAID Assessment projections, please see the full Technical Report.

Mean Annual Changes

The maps and graphs shown in Figures 6 and 7 display temperature, precipitation, and sea level rise projections, based on a range of climate models and scenarios of possible future GHG concentrations. Table 2 and Figure 8 display both the global climate model-based sea level rise projections and a second set of higher projections (the rapid ice-melt scenario) based on the possibility of accelerated melting of land-based ice sheets and glaciers.

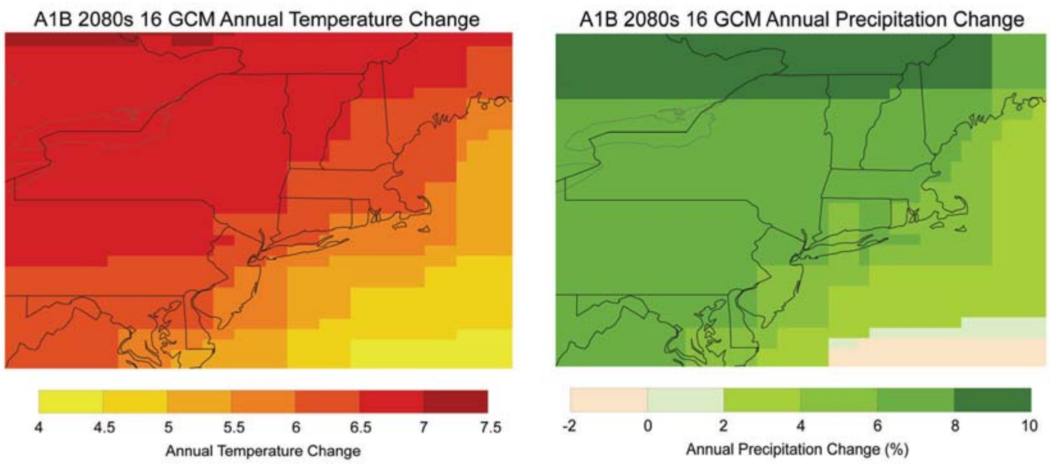


Figure 6. Projected Change in Annual Temperature and Precipitation in the Northeast for the 2080s, Relative to the 1980s Baseline (Under the A1B Emissions Scenario)

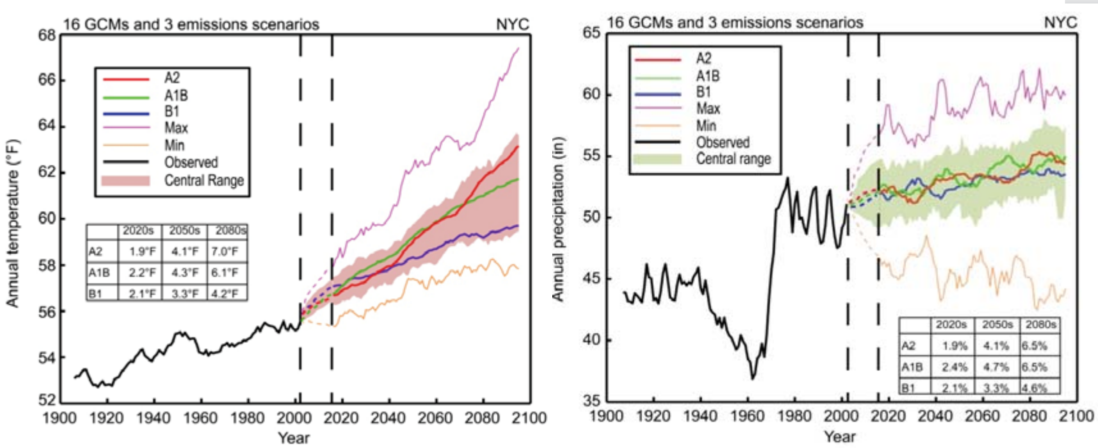


Figure 7. Temperature and Precipitation Observations and Projections for the New York City Area (ClimAID Region 4)

Projected model changes through time are applied to the observed historical data. The three thick lines (green, red, and blue) show the average for each emissions scenario across the 16 GCMs. Shading shows the central range (middle 67%). The bottom and top lines, respectively, show each year s minimum and maximum projections across the suite of simulations. A ten year filter has been applied to the observed data and model output. The dotted area between 2003 and 2015 represents the period that is not covered due to the smoothing procedure.

Region 4: Lower Hudson Valley & Long Island	Baseline (1971–2000)	2020s	2050s	2080s
Sea level rise[1] GCM-based	NA*	+ 2 to 5 in**	+ 7 to 12 in	+ 12 to 23 in
Sea level rise[2] Rapid ice-melt	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in
Region 5: Mid Hudson Valley & Capital Region	**Baseline (1971 – 2000)**	**2020s**	**2050s**	**2080s**
Sea level rise[1] GCM-based	NA	+ 1 to 4 in	+ 5 to 9 in	+ 8 to 18 in
Seal level rise[2] Rapid ice-melt	NA	~4 to 9 in	~ 17 to 26 in	~ 37 to 50 in

Table 2. Sea Level Rise Projections

***NA: not applicable**
****in: inch**

[1] The central range (middle 67 percent) of values from GCM-based probabilities rounded to the nearest inch is shown.
[2] The rapid ice-melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

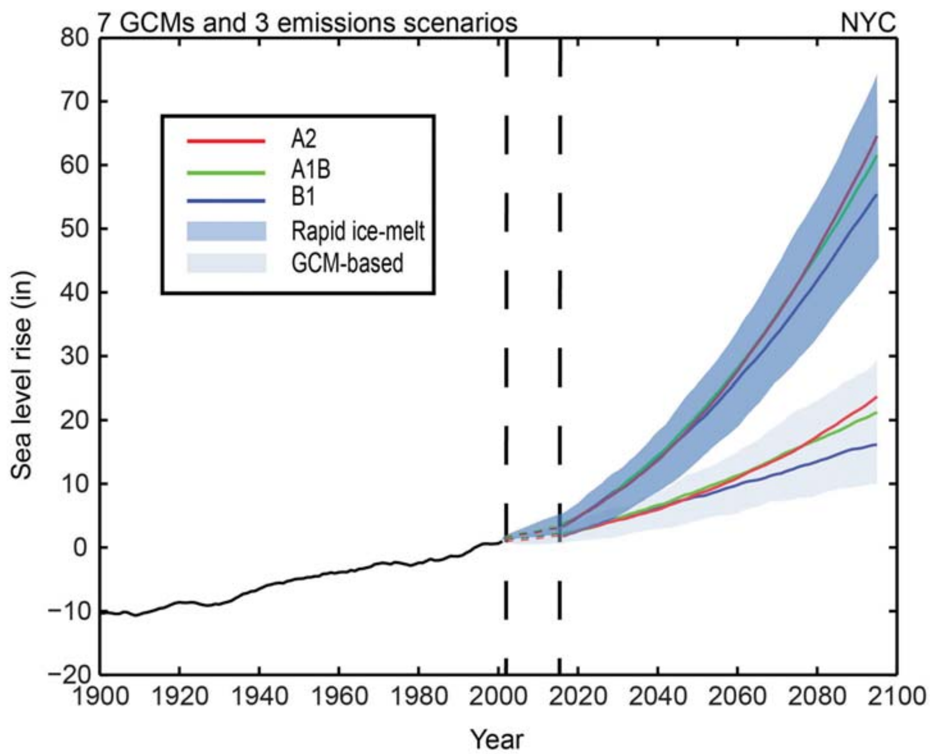


Figure 8. Sea Level Rise Observations and Projections Using Global Climate Model-Based and Rapid Ice-Melt Scenario

Combined observed (black line) and projected sea level rise for two future sea level rise scenarios. Projected global climate model (GCM) changes through time are joined to the observed historical data. Dark blue shows the range of projections for the NPCC rapid ice melt scenario, while light blue shows the range of projections for the GCM based sea level rise approach. The three thick lines (green, red, and blue) within each sea level rise scenario show the average for each emissions scenario across 7 GCMs. A ten year filter has been applied to the observed data and modeled output.

Higher temperatures and sea level rise are extremely likely for New York State in the future. All global climate models project continuing temperature and sea level rise increases over the century, with the central range (the middle 67 percent of all projections) projecting more rapid temperature and sea level rise than what occurred over the 20th century. Although most projections indicate small increases in precipitation, some do not, and decade-by-decade precipitation variability is large; therefore, precipitation projections are less certain than temperature projections.

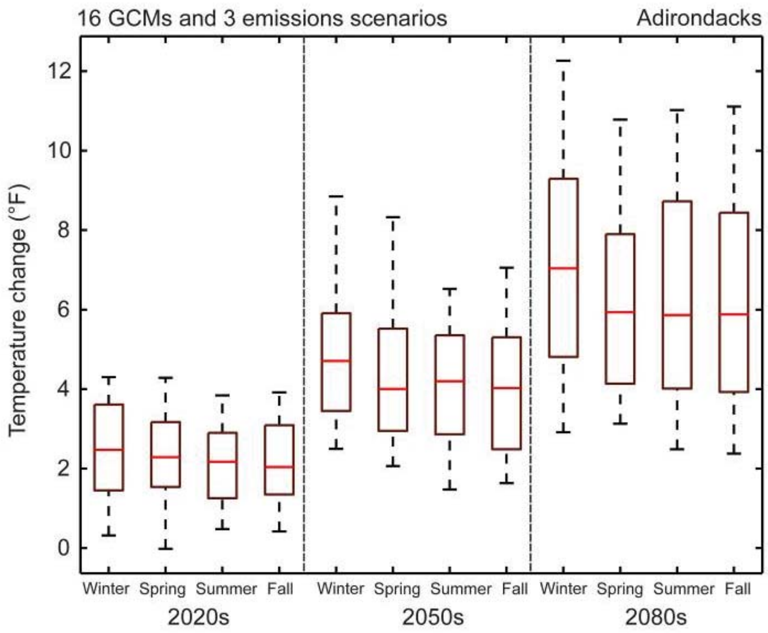
Region-specific projections of mean changes in temperature and precipitation are provided in Table 3. Figure 9 shows seasonal projections for the Adirondacks (ClimAID Region 7).

		Baseline[1] 1971–2000	2020s	2050s	2080s
Region 1					
Stations used for Region 1 are Buffalo, Rochester, Geneva and Fredonia.	Air temperature[2]	48ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.5 to 8.5ºF
	Precipitation	37 in	0 to +5%	0 to +10%	0 to 15%
Region 2					
Stations used for Region 2 are Mohonk Lake, Port Jervis, and Walton.	Air temperature[2]	48ºF	+1.5 to 3.0ºF	+3.0 to 5.0ºF	+4.0 to 8.0ºF
	Precipitation	48 in	0 to +5%	0 to +10%	+5 to 10%
Region 3					
Stations used for Region 3 are Elmira, Cooperstown, and Binghamton.	Air temperature[2]	46ºF	2.0 to 3.0ºF	+3.5 to 5.5ºF	+4.5 to 8.5ºF
	Precipitation	38 in	0 to +5%	0 to +10%	+5 to 10%
Region 4					
Stations used for Region 4 are New York City (Central Park and LaGuardia Airport), Riverhead, and Bridgehampton.	Air temperature[2]	53ºF	+1.5 to 3.0ºF	+3.0 to 5.0ºF	+4.0 to 7.5ºF
	Precipitation	47 in	0 to +5%	0 to +10%	+5 to 10%
Region 5					
Stations used for Region 5 are Utica, Yorktown Heights, Saratoga Springs, and the Hudson Correctional Facility.	Air temperature[2]	50ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.0 to 8.0ºF
	Precipitation	51 in	0 to +5%	0 to +5%	+5 to 10%
Region 6					
Stations used for Region 6 are Boonville and Watertown.	Air temperature[2]	44ºF	+1.5 to 3.0ºF	+ 3.5 to 5.5ºF	+4.5 to 9.0ºF
	Precipitation	51 in	0 to +5%	0 to +10%	+5 to 15%
Region 7					
Stations used for Region 7 are Wanakena, Indian Lake, and Peru.	Air temperature[2]	42ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.0 to 9.0ºF
	Precipitation	39 in	0 to +5%	0 to +5%	+5 to 15%

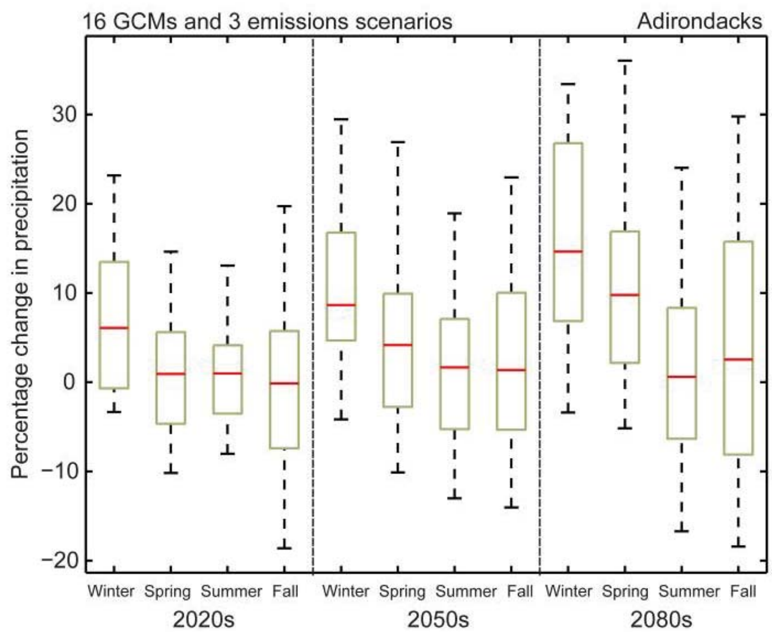
Table 3. Projections of Mean Annual Changes in Air Temperature and Precipitation for New York State Climate Regions

[1] The baselines for each region are the average of the values across all the stations in the region.
[2] The central range (middle 67 percent) of values from model-based probabilities is shown; temperature ranges are rounded to the nearest half-degree and precipitation to the nearest 5 percent.

Source: Columbia University Center for Climate Systems Research. Data are from USHCN and PCMDI.



Increases in temperature are projected to be approximately the same across all seasons



Increases in precipitation may be greatest in winter

Figure 9. Seasonal Temperature Projections for the Adirondacks (ClimAID Region 7)

The full range of values across the 16 GCMs and three emissions scenarios and key points in the distribution are shown here. The central 67 percent of values are shown in the boxed areas; the median is indicated by the red line. Winter runs from December to February, while Spring runs from March through May, Summer from June through August, and Fall from September through November.

Extreme Events

Extreme events can have disproportionate effects on both urban and rural systems throughout New York State. During the 21st century:

- Heat waves are expected to become more frequent and intense
- Intense precipitation events are expected to become more frequent
- Storm-related coastal flooding is expected to increase due to rising sea levels

Table 4 presents projections for some extreme events for the Southern Tier (ClimAID Region 3).

Elmira (Region 3): Full range of changes in extreme events: minimum, (central range*), and maximum					
	Extreme event	Baseline	2020s	2050s	2080s
Heat Waves & Cold Events	Number of days per year with maximum temperature exceeding				
	90°F	10	11 (14 to 19) 25	15 (21 to 33) 45	19 (26 to 56) 70
	95°F	1	2 (2 to 4) 7	2 (4 to 10) 18	4 (7 to 24) 38
	Number of heat waves per year[2]	1	1 (2 to 3) 3	2 (3 to 4) 6	2 (3 to 8) 9
	average duration	4	4 (4 to 5) 5	4 (4 to 5) 5	4 (5 to 5) 7
	Number of days per year with min. temp. at or below 32°F	152	116 (122 to 124) 145	86 (106 to 122) 168	68 (87 to 114) 124
Intense Precipitation	Number of days per year with rainfall exceeding:				
	1 inch	6	5 (6 to 7) 8	5 (6 to 7) 8	5 (6 to 8) 10
	2 inches	0.6	0.5 (0.6 to 0.9) 1	0.5 (0.6 to 1) 1	0.4 (0.7 to 1) 2

Table 4. Extreme Event Projections for the Southern Tier

The minimum, central range (middle 67 percent), and maximum of values from global climate model based probabilities across the GCMs and GHG emissions scenarios are shown.

[1] Decimal places are shown for values less than 1, although this does not indicate higher precision/certainty. The high precision and narrow range reflect model-based results. Due to multiple uncertainties, actual values and range are not known to the level of precision shown in this table.
[2] Defined as three or more consecutive days with maximum temperature exceeding 90°F.

Extreme Event	Probable Direction Throughout 21st Century	Likelihood[1]
Heat Index[2]	^	Very likely
Ice storms/Freezing rain	^	About as likely as not
Snowfall frequency & amount	v	Likely
Downpours (precipitation rate/hour)	^	Likely
Lightning	Unknown	
Intense hurricanes	^	More likely than not
Nor'easters	Unknown	
Extreme winds	^	More likely than not

Figure 10. Qualitative Changes in Extreme Events for New York City/Long Island (ClimAID Region 4)

Potential for changes in other variables are described in a more qualitative manner, as quantitative information is either unavailable or considered less reliable. Figure 10 shows the likelihood of each of these changes occurring in New York City/Long Island.

[1] Likelihood definitions: Very likely = >90 percent probability of occurrence; Likely = >66 percent probability of occurrence; More likely than not = >50 percent probability of occurrence.
[2] The National Weather Service uses a heat index related to temperature and humidity to define the likelihood of harm after prolonged exposure or strenuous activity (http://www.weather.gov/om/heat/index.shtml).

IV. Adaptation Assessment Steps

Adaptation to climate change focuses on actions that stakeholders take in response to a changing climate. Adaptation strategies do not directly include actions that reduce the likelihood of climate change from occurring (i.e., climate change *mitigation*) but instead present actions to lessen the impact of climate change or take advantage of changes unleashed by a shifting climate. In the context of the ClimAID assessment, the ClimAID team examined the following two categories of adaptation strategies:

- Those that reduce the level of physical, social, or economic impact of climate change and variability
- Those that take advantage of new opportunities emerging from climate change

The process of adaptation assessment can be summarized in an eight-step process (see Figure 11), which can be adjusted as needed depending on varying circumstances.

1. Identify current and future climate hazards
2. Inventory vulnerabilities and opportunities
3. Prioritize vulnerabilities
4. Identify and categorize adaptation strategies
5. Evaluate and prioritize adaptation strategies
6. Link strategies to capital and rehabilitation cycles
7. Create an adaptation plan
8. Monitor and reassess

Developing adaptation strategies starts with learning about current climate and how climate is projected to change in the future (see Section III). After understanding how the climate in New York State is projected to change, the next step in developing adaptation strategies is identifying the vulnerabilities a change in climate might create, as well as assessing risk levels. Vulnerabilities and risks can then be prioritized based on several criteria. The risk ratings resulting from the process of prioritizing vulnerabilities can help in the development of adaptation strategies. Several different types of adaptation strategies can be developed in response to a particular climate risk, and a set of factors can be used to evaluate and prioritize these strategies. The final step of the adaptation process is monitoring and reassessing climate changes, impacts, and adaptation strategies (see Figure 11).

These adaptation assessment steps are intended to be general enough to be useful for a range of jurisdictions and infrastructure sectors, yet specific enough to serve as the template for developing and implementing a sector's adaptation efforts. These steps may be used to develop climate change adaptation in any urban area, with region-specific adjustments related to climate risk information, critical infrastructure, and protection levels.

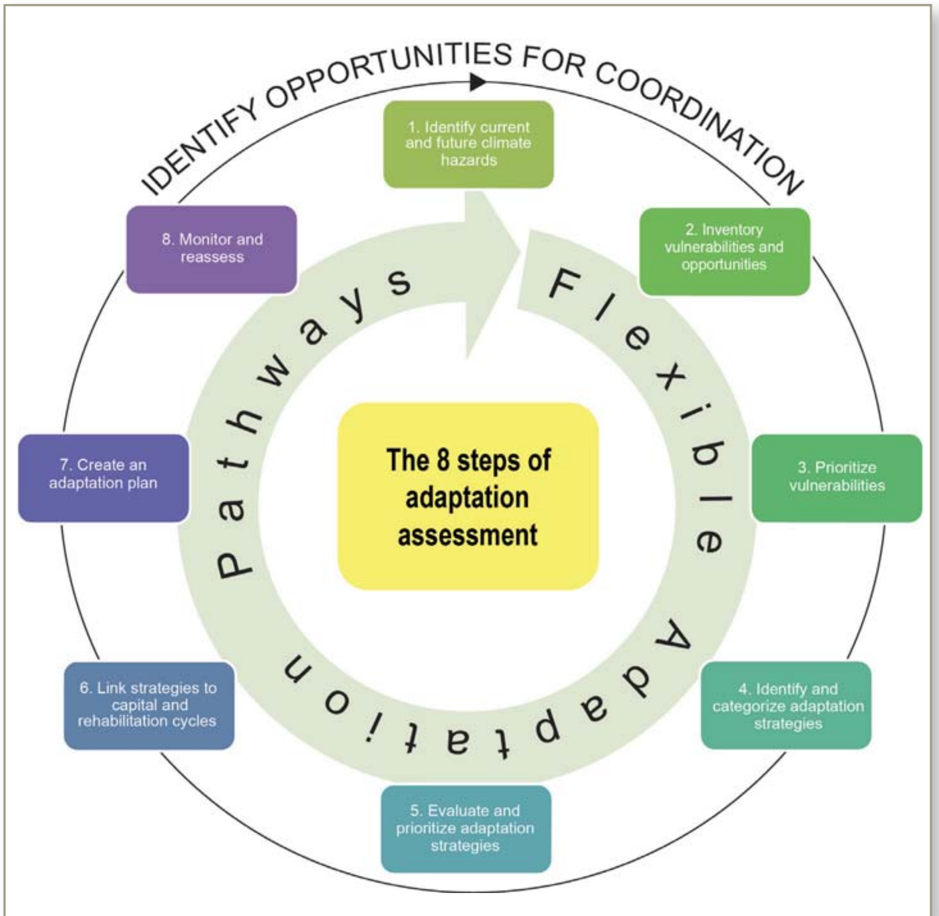


Figure 11. Adaptation Assessment Steps

Step 1: Identify Current and Future Climate Hazards

The first step in developing adaptation strategies is learning about current climate and how climate is projected to change in the future. For more information on the climate of New York State and future projections, see Section III.

Step 2: Inventory Vulnerabilities and Opportunities

A focus on key vulnerabilities is necessary to help policymakers and stakeholders assess the level of risk, prioritize, and design pertinent response strategies. In most instances, inventories of vulnerabilities will be qualitative, based on expert knowledge and relevant climate hazards. Factors that help characterize vulnerability include:

- Magnitude
- Timing
- Persistence and reversibility
- Likelihood
- Distributional aspects
- Importance of the at-risk systems
- Potential for adaptation
- Thresholds or trigger points that could exacerbate the change

Based on these factors, the ClimAID team developed an inventory of key vulnerabilities for New York State; examples of key vulnerabilities for New York State by climate factor, for each of the ClimAID sectors, are shown in Table 5.

Climate Hazard / Sector	Water Resources	Coastal Zones	Ecosystems	Agriculture	Energy	Transportation	Telecommunications	Public Health
Temperature and Heat Waves	Increased wear and tear on materials Potential changes in drinking supply	Shifts in marine species due to warmer waters	Increased frequency of summer heat stress on plants Potential changes in pest populations and habits Changes in species composition due to warmer winters	Changes in distribution of primary crops such as apples, cabbage, and potatoes Decline in dairy milk production	Increased demand on energy supply Increased vulnerability of energy infrastructure	Increased wear and tear on infrastructure Extreme event-related delays and hazards	Increased wear and tear on materials	More heat-related deaths Decline in air quality
Precipitation, Extreme Precipitation, and Drought	Increased vulnerability of infrastructure Potential changes in drinking supply Increased risk of changes in river flooding	Potential permanent inundation of coastal lands, including critical wetland habitat	Potential changes in pest populations and habits	Changes in distribution of primary crops such as apples, cabbage, and potatoes	Increased vulnerability of energy infrastructure Greater uncertainty around future availability of alternative energy sources	Flooding of key rail lines, roadways, and hubs Increased wear and tear of materials Extreme event-related delays and hazards	Flooding of central facilities Increased wear and tear on materials	Outbreaks of illness related to water-borne pathogens
Sea Level Rise and Coastal Flooding	Saltwater intrusion into freshwater aquifers	Increased risk of storm surge-related flooding Potential permanent inundation of coastal lands, including critical wetland habitat	Effects on marine and freshwater species	Salinization of coastal agriculture areas	Increased vulnerability of energy infrastructure	Episodic and permanent inundation of key rail lines, roadways, and hubs Extreme event-related delays and hazards	Flooding of central facilities Increased wear and tear on materials	Direct physical harm and trauma

Table 5. Examples of Key Vulnerabilities for New York State by Climate Factor

Step 3: Prioritize Vulnerabilities

Vulnerabilities are prioritized depending upon those systems or regions whose failure or reduction in function is likely to carry the most significant consequences. One tool used in risk assessment is a matrix that assesses the magnitude of consequence of an event against the likelihood of the event occurring. For climate adaptation assessment, there are at least three layers of uncertainty that need to be considered to yield an approximate overall risk of a particular climate hazard and a particular impact (see Figure 12). The overall risk rating can then assist in the creation of adaptation strategies. Risk categories to be considered include:

Probability of a given climate hazard – The general probability for change in a climate hazard (such as temperatures or extreme precipitation events) occurring. Using climate risk information as a guide, these can be defined as:

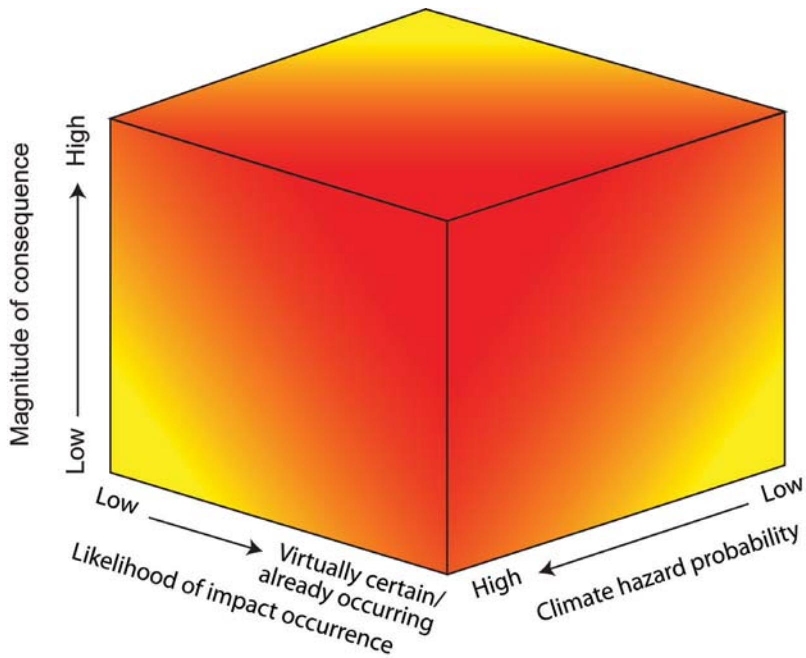
- **High** probability of the climate hazard occurring
- **Medium** probability of the climate hazard occurring
- **Low** probability of the climate hazard occurring

Likelihood of impact occurrence – The likelihood that a change in a given climate hazard (e.g., temperature rise) will result in a particular impact (e.g., material failure). Examples of likelihood categories include:

- **Virtually certain/already occurring** – Nearly certain likelihood of the impact occurring over the useful life of the infrastructure, and/or the climate hazard may already be impacting infrastructure
- **High** likelihood of the impact occurring over the useful life of the infrastructure
- **Moderate** likelihood of the impact occurring over the useful life of the infrastructure.
- **Low** likelihood of the impact occurring over the useful life of the infrastructure.

Magnitude of consequence – The combined impacts should a given hazard occur, taking into account such factors as:

- **Internal operations**, including the scope and duration of service interruptions, reputational risk, and the potential to encounter regulatory problems
- **Capital and operating costs**, including all capital and operating costs to the stakeholder and revenue implications caused by the climate change impact
- **Number of people impacted**, including considerations related to any impacts on vulnerable populations (including, but not limited to seniors, low-income communities, mentally or physically disabled citizens, homebound residents, and children).
- **Public health**, including worker safety
- **Economy**, including any impacts to the city's economy, the price of services to customers, and clean-up costs incurred by the public
- **Environment**, including the release of toxic materials and impacts on biodiversity, the state's ecosystems, and historic sites



RED	*Risks for which adaptation strategies should be developed.*
ORANGE	*Risks for which adaptation strategies may need to be developed or for which further information is needed.*
YELLOW	*Risks for which impacts should be monitored but which may not need actions at this time.*

Figure 12. Three-Dimensional Climate Risk Assessment Matrix

Step 4: Identify and Categorize Adaptation Strategies

Building on internal risk-management and assessment policies, stakeholders can begin to brainstorm strategies for those infrastructure classes that fall into the red and orange categories of the risk matrix (Figure 13). Adaptation strategies may be divided into a set of categories, including:

- The **type** of adaptation strategy depends on whether the strategy is focused on management and operations, infrastructural change (particularly with the physical component of the sector), or policy adjustments.
- The **administration** element of adaptation strategies defines the strategy as either emerging from the public or private sectors, and from which level of government (i.e., local/municipal, county, state, or national).
- **Condition** is defined by whether an adaptation strategy is an incremental action or a larger-scale paradigm shift.
- **Timing** highlights the period during which the adaptation strategy will be implemented. Given what is understood about the rate of climate change and the sensitivities of the system, a primary question is whether the adaptation should take place in the short term (less than 5 years), medium term (5 to 15 years), or long term (more than 15 years). A crucial consideration regarding the issue of timing is whether there are tipping points associated with dramatic shifts

in the level of impacts and/or vulnerabilities and whether these tipping points become triggers for new policies and regulations.

- **Geography** relates to the overall spatiality of the adaptation impacts, specifically, cataloging if the adaptation strategy is widespread, clustered, or isolated/unique (e.g., if the impact is associated with a specific site or location) throughout the state.

Potential adaptation strategies can be further defined within a range of elements including economics and institutional organization. Economic issues include the costs and benefits of adaptation, and the relative distribution of both. A critical economic issue is the overall cost-to-benefit ratio and how much economic advantage there is to taking a specified action. It is also important to determine potential opportunity costs, as well as the capacity (e.g., human and capital resources) and capability (e.g., regulatory mandate, legal ability) of the entity considering the adaptation.

Step 5: Evaluate and Prioritize Adaptation Strategies

Prioritization of which adaptation to undertake is a critical component of developing an adaptation strategy. Prioritization criteria include considerations of climate risk levels, vulnerability and exposure, maximum benefit-cost ratio, cost effectiveness, distributional and equity concerns, and institutional capacity and capability. Other criteria include the spatial and temporal character of a strategy's impact and the potential for flexible adaptation.

There may be multiple strategies to consider during adaptation planning. Once stakeholders have an initial list of adaptation strategies, they can evaluate these strategies in order to determine an order in which they should be implemented, and begin to create a broader agency- or organization-wide adaptation plan. There are a variety of available methods and perspectives to aid in evaluating individual actions and strategies (see example in Table 6). Elements to consider as part of evaluating adaptation strategies could include:

- **Cost** – What are the general costs of the proposed strategy, including human and other resources? General costs can yield a rough measure of benefits and costs to the extent that the consequences are measured in economic terms. There will also be important non-economic consequences in most decision problems.
- **Timing** – Timing of implementation should be considered relative to the timing of impact. Specifically, if the impact will occur in a time frame comparable to the time required for implementation, there is need for immediate consideration.
- **Feasibility** – How feasible is the strategy for implementation both within an organization and from perspectives such as engineering, policy, legal, and insurance? Are there expected technological changes that would impact future feasibility?
- **Efficacy** – To what extent will the strategy, if successfully implemented, reduce the risk?
- **Robustness** – Is there the potential to install equipment or upgrade infrastructure that is designed to withstand a range of climate hazards? Are there opportunities for flexible adaptation pathways?
- **Co-benefits** – Will strategies have a negative or positive impact on other stakeholders or sectors? Is there potential for cost sharing? Are there impacts on mitigation of greenhouse gases? Are there impacts on the environment or a vulnerable population?

Other factors to consider include equity, social justice, sustainability, institutional context, and unique circumstances.

Adaptation Strategy	Strategy Cost (1=low to 3 high)	Strategy Feasibility (1=low to 3 high)	Timing of implentation (1=low to 3 high)	Efficacy (1=low to 3 high)	Resiliency rating (1=low to 3 high)	Co-benefits (1=low to 3 high)	Average*	Notes & institutional considerations
Clean drains	1	1	1	2	2	2	1.8	
Build flood walls	3	2	2	1	3	2	2.2	

Table 6. Strategy Prioritization Framework with Adaptation Strategy Examples

***1=high priority strategy, 2=medium priority strategy, 3 low priority strategy**

Source: NPCC (2010)

Step 6: Link Strategies to Capital and Rehabilitation Cycles

Stakeholders have capital budgets that extend over a variety of time periods; in some cases, budgets extend over decades. Stakeholders should review these budgets to determine which adaptation strategies can be undertaken within existing funding constraints and what additional resources need to be identified. Linking adaptation strategies to planned projects or other non-adaptation efforts can result in significant cost savings. In turn, stakeholders are advised to put priority on exploring low-cost adaptation strategies, especially in times of fiscal austerity.

Step 7: Create an Adaptation Plan

The conclusion of the climate adaptation assessment process is really just the beginning. Stakeholders can combine and distill the knowledge gained from the assessment into an adaptation plan, which, in turn, can help operationalize adaptation planning.

An adaptation plan could include the following components:

- Discussion of key climate vulnerabilities
- List of prioritized adaptation strategies
- Consideration of other adaptation tools
- Plan for establishing indicators and monitoring
- Timeline to reassess strategies as new information comes to light

An adaptation plan should be seen as a living document and be revisited on a semi-regular basis to ensure that it incorporates the latest research and knowledge. By doing so, stakeholders can develop flexible adaptation pathways that lead to an ongoing adaptive capacity for systems, sectors, regions, and groups.

Step 8: Monitor and Reassess

Monitoring climate change on a regular basis, as well as other factors that might directly or indirectly influence climate change risks, will help development of flexible adaptation pathways. Consistent monitoring protocols are needed for climate change indicators, particularly those related to changes in the climate, climate science updates, climate impacts, and adaptation activities. Monitoring of key indicators can help stakeholders initiate course corrections in adaptation policies and/or changes in timing of their implementation. These indicators need to be developed and tracked over time to provide targeted quantitative measures of climate change, its impacts, and adaptation. This will provide useful information to decision-makers regarding the timing and extent of needed adaptation actions.

V. Other Adaptation Tools

There are other climate change adaptation tools to consider that include regulatory, design, and engineering standards; legal structures; and insurance opportunities.

Climate Protection Levels

Climate protection levels (CPLs) refer to building and construction codes and regulations, design standards, and best practices that pertain to climate, as adopted by the professional engineering community and various government entities.

The general framework for the development of CPLs and/or recommendations for future study are summarized in the following steps:

1. Develop regional/local-specific climate change projections.
2. Select climate hazards of focus (e.g., coastal flooding and storm surge, inland flooding, heat waves, and extreme events).
3. Solicit feedback from operators and regulators of infrastructure through questionnaires to identify potential impacts of climate change hazards on infrastructure.
4. Identify existing design and/or performance standards relevant to critical infrastructure
5. Review and reassess these standards in light of the climate change projections.
6. Highlight those standards that may be compromised by climate change and/or need further study to determine if revised CPLs are necessary to facilitate climate resiliency.

To meet the criteria for development of a recommended CPL, a regulation, policy, or practice needs to:

- Guide the formation or maintenance of critical infrastructure at risk to climate-related hazards.
- Dictate action in order to maintain acceptable risk levels with respect to climate-related hazards.
- Allow for adjustments that will enable a stable level of risk protection in response to a changing climate.

CPL recommendations can take multiple forms and offer content that is broad-based, design-specific, measurable/quantifiable, policy relevant, or suggestive of future studies. The following examples illustrate the types of recommendations for CPLs:

- **Quantitative statements** – Statements that emerge from the interplay between quantitative design, performance standards, and quantitative climate risk information.
- **General statements** – Narrative comments on the relevance of climate risk information to existing design standards.
- **Infrastructure analysis** – Recommendations for further analysis of critical parts of the infrastructure for which more information is needed to create CPLs. For example, more specific information on the existing design standards of street catch basins for inland street level flooding is required to determine if a CPL is needed to address the issue.
- **Engineering-based studies** – Suggestions for engineering studies such as hydrologic studies that need to be performed in order to determine if and/or how current standards need to be changed. These are necessary in situations where there are limitations in the knowledge of the system/material-level response to climate change and variability (e.g., responses of materials to increased heat).
- **Policy and planning issues** – Evaluation of system-wide processes such as the distribution of impervious surfaces, land-use changes, and public health alerts.

Legal Framework

Another climate change adaptation tool is the updating of laws and legal frameworks that guide planning, zoning, building codes, health codes, and materials usage. In many cases, the addition of a climate change component to an Environmental Impact Statement or equivalent regulation could be an efficient way to encourage the consideration of climate change impacts. Current federal, state, and local laws could be reassessed; new regulations should incorporate climate change into their formulations.

Insurance

Insurance can be a powerful risk-sharing tool for climate adaptation. Insurance companies are now being brought into discussions about climate change adaptation. As an example, insurance companies influence the level of development in coastal areas. If potential future changes in sea level rise are taken into account, insurance companies could factor these risks into their hazard models and help to disperse certain risks associated with climate change.

VI. Summary

The risk-management adaptation strategies described in this guidebook will be useful in helping stakeholders reduce climate impacts in the future. Climate change is extremely likely to bring warmer temperatures to New York State, while climate hazards are likely to produce a range of impacts on the urban and rural fabric of the state in the coming decades. Heat waves are very likely to become more frequent, intense, and longer in duration. An increase in total annual precipitation is more likely than not; brief, intense rainstorms are also likely to increase. Additionally, rising sea levels are extremely likely, and are very likely to lead to more frequent and damaging flooding related to coastal storm events in the future.

It is important to note that adaptation strategies are also likely to produce benefits today, as such strategies will help to lessen impacts of climate extremes that cause current damage. Given the scientific uncertainties in projecting future climate change, however, monitoring of climate and impacts indicators is critical so that flexible adaptation pathways for the region can be achieved.

Climate variables should be monitored and assessed on a regular basis. Indirect climate change impacts, such as those caused by climate change in other regions, should also be taken into consideration. By evaluating this evolving information, New York State can be well positioned to develop robust and flexible adaptation pathways that maximize climate and societal benefits while minimizing climate hazards and costs.

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Climate Adaptation Guidebook for New York State

November 2011

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Andrew M. Cuomo, Governor

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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).

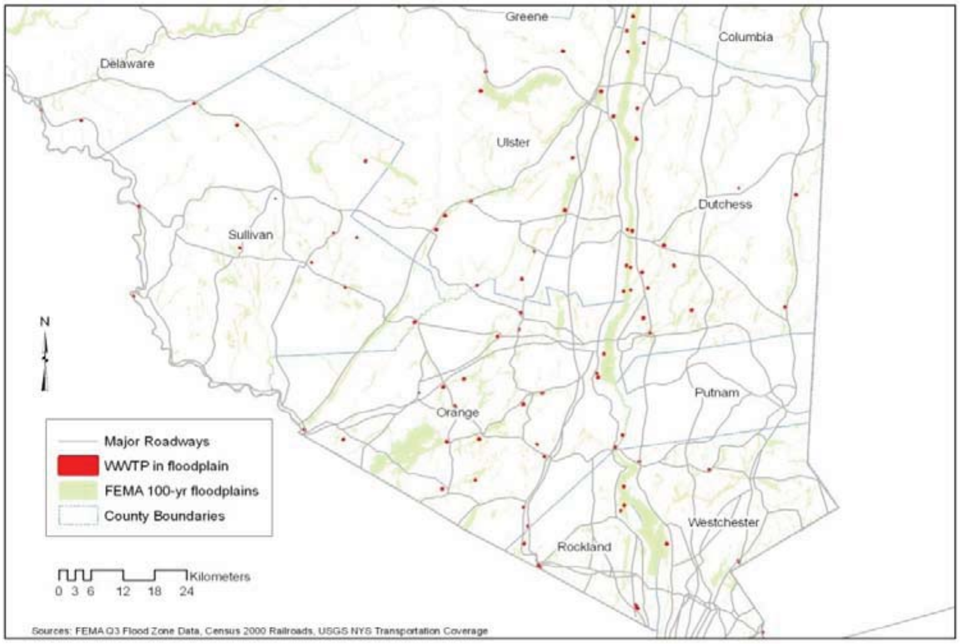

Figure 2.1. WWTPs in close proximity to floodplains in the Hudson Valley and Catskill Region. WWTPs along the Hudson are at risk from sea level rise and accompanying storm search.

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			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			
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: Temperature	Precipitation	Extreme Events: rainfall	Sea Level Rise	Atmospheric CO_2	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
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: Temperature	Main Climate Variables: Precipitation	Main Climate Variables: Extreme Events: rainfall	Main Climate Variables: Sea Level Rise	Main Climate Variables: Atmospheric CO_2	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
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.

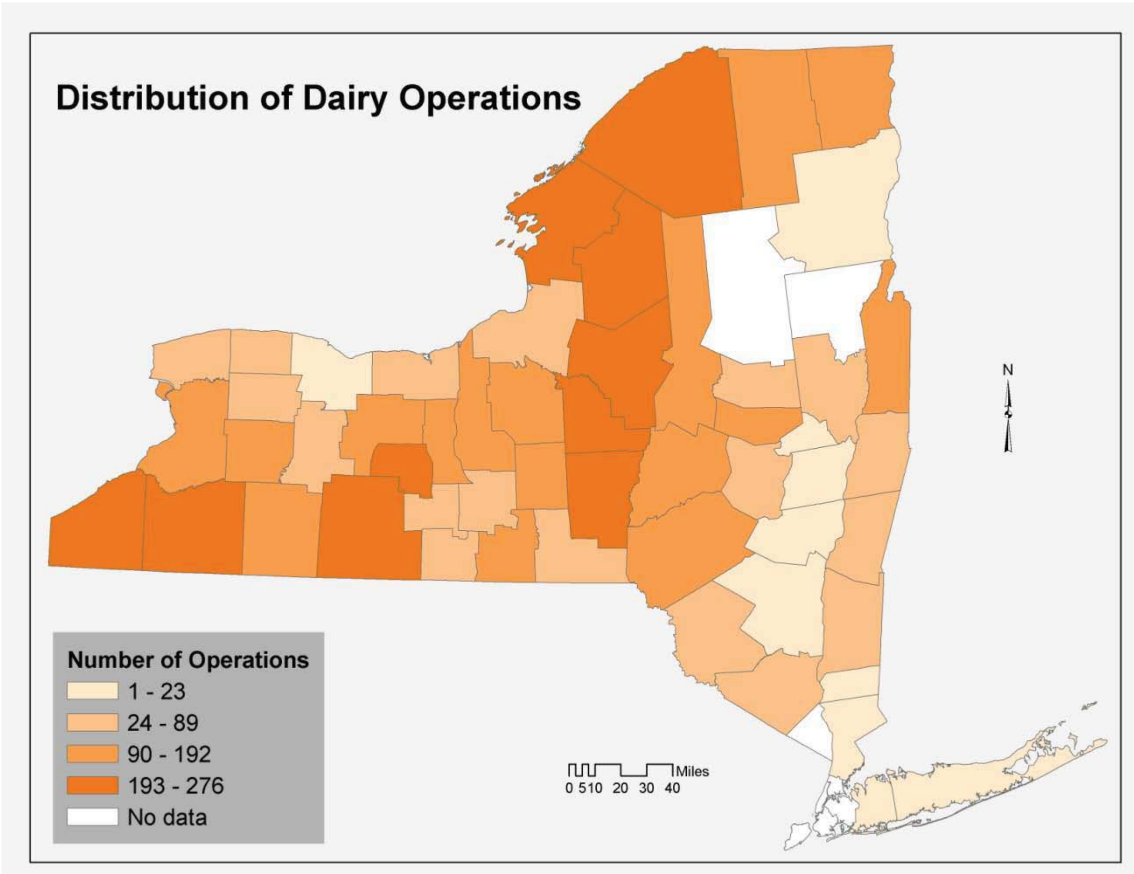

Figure 5.1. Locations of dairy operations in New York State.
Source: USDA 2009.

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	Precipitation	Sea Level Rise	Extreme Events: Heat	Extreme Events: Intense Precipitation	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 Cost	Interruption Duration				
	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: Temperature	Main Climate Variables: Precipitation	Main Climate Variables: Sea Level Rise & Storm Surge	Main Climate Variables: Atmospheric CO_2	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
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				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
	Extreme Events: Heat	Extreme Events: Ice and Snow Storms	Extreme Events: Hurricanes, Rain, Wind & Thunderstorms	Electric Power Blackout			
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:

	Analyzed example
	Analogous number or order of magnitude
	Qualitative information
	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 futu re 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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Responding to Climate Change in New York State

Technical Report

Final Report 11-18
November 2011

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