REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

Mainstreaming Climate Change Adaptation Strategies into New York State Department of Transportation's Operations: Final Report

October 31, 2011

Prepared for the New York State Department of Transportation
by

David C. Major, Ph. D.[1*], Rae Zimmerman, Ph.D.[2], John Falcocchio, Ph.D.[3], Klaus Jacob, Ph.D.[1], Radley Horton, Ph.D.[1], Megan O'Grady[1], Daniel Bader[1], Joseph Gilbride[1], and Taylor Tomczyszyn[1]

* Principal Investigator
1 Columbia University Earth Institute, Center for Climate Systems Research, Armstrong Hall
2 New York University, Robert F. Wagner Graduate School of Public Service
3 Polytechnic Institute New York University

Columbia University Earth Institute
Center for Climate Systems Research
Armstrong Hall 2880 Broadway NY NY 10025
Research Project No. C-08-09

NYSDOT RESEARCH PROJECT C-08-09

NYSDOT TECHNICAL WORKING GROUP

O. (Sam) A. Elrahman, Ph.D., Project Manager
Arthur Sanderson, P.E.
Pratip Lahiri, P.E.
Darrin Moret
Lisa Pelcher

DISCLAIMER

This report was funded in part through grant(s) from the Federal Highway Administration, United States Department of Transportation, under the State Planning and Research Program, Section 505 of Title 23, U.S. Code. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The contents do not necessarily reflect the official views or policies of the UTRC or the Federal Highway Administration. This report does not constitute a standard, specification or regulation. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2.Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Mainstreaming Climate Change Adaptation Strategies into New York State Department of Transportation's Operations		5. Report Date 10/31/11 6. Performing Organization Code	
7. Author(s) David C. Major, Ph. D., Rae Zimmerman, Ph.D., John Falcocchio, Ph.D., Klaus Jacob, Ph.D., Megan O'Grady, Radley Horton, Ph.D., Daniel Bader, Joseph Gilbride, and Taylor Tomczyszyn		8. Performing Organization Report No.	
9. Performing Organization Name and Address Columbia University Earth Institute Center for Climate Systems Research, Armstrong Hall, 2880 Broadway, New York NY 10025		10. Work Unit No. 11. Contract or Grant No. 55505-01-02	
12. Sponsoring Agency Name and Address New York State Department of Transportation, 50 Wolf Road, Albany NY		13. Type of Report and Period Covered 14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract This study identifies climate change adaptation strategies and recommends ways of mainstreaming them into planned actions, including legislation, policies, programs and projects in all areas and at all levels within the New York State Department of Transportation (NYSDOT). In accomplishing its goal, the study team relied on: a literature review; discussions with key NYSDOT personnel based on a Climate Risk Information Summary worksheet; information from other ongoing and completed projects in climate change adaptation, especially those in the New York region; and advice and guidance from the NYSDOT's Technical Working Group and Columbia's Advisory Working Group for the project. The results of the project are presented (following the Introduction) in terms of: the current understanding of climate change science and climate futures for New York State; climate change impacts and vulnerabilities to transportation in NYS; adaptation strategies and best practices; potential adaptation strategies for mainstreaming climate change into the NYSDOT's operations and investment, including the detailed results of climate risk management discussions with personnel from 2 Divisions, 12 Offices, and 1 Region; and a communications and technology transfer plan.			
17. Key Words Climate change; transportation planning; New York State Dept. of Trans.; main-streaming adaptation; vulnerabilities	18. Distribution Statement Unlimited		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No of Pages 116	22. Price

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

Foreword

The concept of mainstreaming climate change adaptation strategies emerged from the realization that a proactive response to climate change is critical. It recognizes that for any response to be effective and sustainable, it must avoid existing as a separate, isolated entity which is constantly striving to impose itself on existing practices, operations, procedures and protocols. It must be fully integrated and *mainstreamed*. In other words, the objective of mainstreaming climate change adaptation strategies is to make climate change considerations an integral component of the design, implementation, monitoring and evaluation of policies and programs at all levels of NYSDOT. By adopting a mainstreaming approach, one can ensure that climate change adaptation is not an afterthought, but is integrated into planning, resource allocation, policy development, engineering and operations.

While mainstreaming climate change adaptation strategies is not a goal in itself, it is a means of achieving the goal of maintaining a transportation system that is resilient to climate change. It is a tool which will make our transportation system prepared and ready to address the inevitable consequences of climate change.

Sponsored by NYS Department of Transportation and developed by Columbia University, this study represents a preliminary step in implementing this strategy. It provides a review of relevant literature, documents conversations with NYSDOT leaders, and provides general recommendations to the Department. The recommendations represent useful directions for next steps in the areas of policies and guidelines; organization and management; inter and intra-agency coordination; regional aspects of adaptation planning; development of inventories of vulnerability; design; structural adaptation; monitoring and assessment; training; communication; and research.

The report will hopefully provide an impetus to continue to move forward with further exploring the most effective way of mainstreaming climate change adaptation into all levels of the Department's operations and making it everyone's business.

NYSDOT TECHNICAL WORKING GROUP

O. (Sam) A. Elrahman, Ph.D., Project Manager
Arthur Sanderson, P.E.
Pratip Lahiri, P.E.
Darrin Moret
Lisa Pelcher

Acknowledgments

The authors acknowledge with gratitude the members of the NYSDOT's Technical Working Group for this project, led by the Project Manager, Sam Elrahman, Ph.D. and including Arthur Sanderson, P.E., Pratip Lahiri, P.E., Darrin Moret, and Lisa Pelcher. The members of the TWG provided excellent guidance throughout the period of the work. The authors also are grateful to the senior staff members of NYSDOT who participated in interviews and in many cases provided editorial suggestions for the report: Louis Adams, Donald Baker, James Bridges, George Christian, Robert Dennison, Joseph Foglietta, Donald Hannon, Robert Hansen, Mary Ivey, Elisabeth Kolb, Richard Lee, Keith Martin, Gary McVoy, Jan Meilhede, John Rowen, Robert Sack, Robert Selover, James Tynan, Todd Westhuis, Coleen Smith Lemmon, and John Zamurs. Two members of the Columbia Advisory Working Group who are not among the report's authors, Dr. Cynthia Rosenzweig and Dr. William Solecki, provided helpful overall perspectives throughout the work.

Executive Summary

This study is aimed at identifying climate change adaptation strategies and recommending ways of mainstreaming them into every planned action, including legislation, policies, programs and projects in all areas and at all levels within the New York State Department of Transportation (NYSDOT). The study was funded by the NYSDOT through the University Transportation Research Center, Region II, with additional resources from Columbia University.

Observations and conclusions from the study include the following:

- The principal climate changes that will impact New York State are sea level rise, higher temperatures, and potential increases in the intensity of coastal and inland storms.

- Impacts on transportation from changing climate include permanent inundation of facilities from rising seas; more frequent and extensive flooding of facilities from coastal storms; increased flooding and downtime from potentially more intense inland and urban storms; and stresses on facilities from increased heat.

- The current state of the NYSDOT's climate change adaptation activity is one of forward movement, as evidenced by the Adapting to Climate Change Working group that was established as part of the NYSDOT's Climate Change and Energy Efficiency (CC & EE) Initiative, the formation of the Sustainability and Climate Change Section in the Policy and Planning Division, and executive management involvement in the development of the NYS Climate Action Council's Climate Action Plan (Interim Report, 2010).

- There will be a continuing need for an ongoing internal structure at the NYSDOT to deal with mainstreaming climate change adaptation over the next few years. The newly formed Sustainability and Climate Change Section is to lead this effort, which can include expanding the current CC & EE Team structure to include a senior person from each key division and the regions to constitute an Adaptation Team. This group could meet regularly as an officially constituted team to map out the needs for climate change adaptation planning in each part of the NYSDOT.

- An immediate challenge for the NYSDOT is to develop organizational, training and outreach efforts that will initially help to achieve recommendations for mainstreaming climate change into NYSDOT planning and programs.

- These immediate challenges can be met with a reasonable level of resources and guidance of the Sustainability and Climate Change Section and the CC & EE Initiative, inclusive of a steering committee.

- A next level of effort, achievable but more challenging, is the revision of engineering and operational protocols and the actual implementation of adaptive management practices as climate change develops.

- NYSDOT infrastructure designs should be appropriate to the expected schedule of implementation, because the appropriate design should be based on the climate variables and impacts expected at the date of implementation and beyond.

- Designs for rehabilitation and replacement of facilities will need to include climate adaptation planning, a potentially large source of savings in implementation costs as compared to last-minute add-ons.

- There is an immediate need to begin the development of (and provide for the updating of) climate change adaptation planning in all Divisions for the short-, medium- and long-terms. The elements of each of these plans will depend on the longevity of different types of infrastructure, legal mandates, available planning resources, and other factors. These plans should all incorporate the concept of "flexible adaptation pathways," the development of adaptation plans stretching into future time periods that retain flexibility, insofar as possible within the limits of infrastructure design and operation, as climate conditions change.

- Developing climate adaptation plans should be based on the early and detailed inventory and mapping of assets and the detailed examination of vulnerabilities, and adaptation options.

- There is a need for New York State to endorse climate change projections as embodied in the Climate Action Plan to provide the official basis for plans for climate change adaptation. For example, the design of drainage facilities needs to be based on accepted scenarios of storm intensity.

- Monitoring and reassessment both by scientific and operational agencies are critical components of any climate change adaptation plan; monitoring will be both intra- and inter-agency, and reassessment of particular plans will generally be within agencies.

- There are on-going research needs relating in particular to methods of integrating climate change scenarios into the design of programs and projects to insure their adaptability to future conditions; these relate not only to NYSDOT but to other agencies as well. Other research needs are detailed in the Climate Action Plan.

- Finally, the NYSDOT has opportunities to contribute to climate change adaptation mainstreaming in New York State beyond its own direct responsibilities through its membership in Metropolitan Planning Organizations (MPOs), its interactions with local transportation agencies, its local projects program, and other financial support and interagency activities.

A complete summary of the report's recommendations is given below, and suggested division and other office lead roles are given in Table ES.1.

In accomplishing its goal, the study team relied on: a literature review; discussions with key NYSDOT personnel based on the Climate Risk Information Summary worksheet developed cooperatively by the project staff, the NYSDOT's Technical Working Group (TWG), and Columbia's Advisory Working Group (AWG); information from Columbia's many ongoing and completed projects in climate change adaptation, especially those in the New York region; advice and guidance from the NYSDOT's Technical Working Group for the project; and advice and guidance from Columbia's Advisory Working Group.

The results of the project are presented (following the Introduction) in terms of:

- The current understanding of climate change science and climate futures for New York State (Chapter 2)

- Climate change impacts and vulnerabilities to transportation in NYS (Chapter 3)

- Adaptation strategies and best practices (Chapter 4)

- Potential adaptation strategies for mainstreaming climate change into the NYSDOT's operations and investment, including a summary of recommendations and the detailed results of climate risk management discussions with personnel from 2 Divisions, 12 Offices, and 1 Region (Chapter 5), and

- A communications and technology transfer plan (Chapter 6).

Summary of Study Recommendations (Note: the Divisions or other units that can take the lead in implementing the broad categories of recommendations are given in parentheses; these are summarized in a following table.)

A. Planning Policies and Guidelines (Climate Change and Energy Efficiency (CC & EE) Initiative Engineering, Legal Affairs, Operations, Policy and Planning, Sustainability and Climate Change Section,)

1. The development of planning strategies for immediate decisions, for the medium term, and for the long term is an important need.

2. Planning strategies can best be developed within a consistent set of adaptation assessment guidelines, which can be based on national and other guidance as well as through internal deliberations.

3. A risk-based management approach, where risk is defined as the probability of an event multiplied by a measure of its consequence, can be an important element of climate change adaptation in NYSDOT.

4. Specific adaptation strategies may be best undertaken when staged over time to meet changing climate conditions and impacts.

5. Within adaptation strategies, the use of flexible adaptation pathways enables agencies to maximize the effectiveness of adaptations over time.

6. Climate change adaptation can be most cost-effective when incorporated into infrastructure during replacement and rehabilitation. Integrating climate change adaptation into capital plans in this way is an important element of adaptation. Further, NYSDOT can encourage addition of climate change considerations and requirements to SEQRA and CEQR

7. Regional transportation master plans should address the climate change-related revisions of land use.

B. Organization and Management (Climate Change and Energy Efficiency (CC & EE) Initiative, Commissioner's Office, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section,)

1. There will be a continuing need for an ongoing internal structure at the NYSDOT to deal with mainstreaming climate change adaptation over the next few years. The newly formed Sustainability and Climate Change Section is to lead this effort, which can include the expanding the current CC & EE Team structure to include a senior person from each key division and the regions to constitute an Adaptation Team. (Work groups can meet as needed and forward recommendations for review.) Among this teams' tasks could be:

    a. Detailed planning for best-practice identification and incorporation into each element of the NYSDOT.

    b. Leadership in leveraging the need for climate change adaptation into budget requests.

    c. Oversight of training and communications needs.

    d. Identifying and progressing research needs.

2. Management programs, such as emergency response strategies, that deal with current variability can in many cases be expanded over time to deal with climate change. In particular, as extreme events increase due to climate change, there can be a proactive increase in budgets to deal with these.

3. Maintenance of the NYSDOT's systems should be undertaken at a high and continuous level to insure that both current and future facilities are resilient to climate change. This refers both to ongoing maintenance and improvements to bring the systems to a state of good repair.

C. Inter- and intra-agency coordination (Administration, Commissioner's Office, Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Legal Affairs, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Mechanisms for coordination for existing purposes can be identified and expanded to target climate change adaptation.

2. NYSDOT can encourage best-practice identification and incorporation in the groups outside the NYSDOT in which the agency participates such as the Metropolitan Planning Organizations (MPOs).

3. Inconsistencies and conflicts among both internal and interagency programs that may develop as the climate changes can be identified; for example, planned expansions and rebuilding of infrastructure in current coastal and riverine flood plains can be reexamined in the light of climate forecasts.

4. NYSDOT can encourage other agencies to reduce runoff from nearby properties and other right-of-ways onto transportation systems.

5. NYSDOT can participate in writing nationally applicable transportation guidelines or standards to ensure that they contain adequate language and technical content for addressing climate change adaptation (and/or mitigation—NYSCAC, 2010, Ch. 7) needs.

D. Regional aspects of adaptation planning (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Climate scenarios suggest different impacts in different areas of NYS, so that adaptation plans and programs will have to vary to some extent by the regions of the NYSDOT.

2. The most important example of differential effects is the impact of rising sea levels and associated higher storm surges on transportation systems in coastal areas and the Hudson Valley (NYSDOT regions 8, 10 and 11 and a part of 1).

3. Although different regions will need to have somewhat different plans and resources across NYS, these plans and resources should be tied together by the overarching approaches to climate change adaptation suggested in this report.

4. NYSDOT will want to track the effectiveness of and ultimately utilize regional climate models (RCMs) as these become more reliable in identifying smaller scale climate change impacts.

E. Vulnerability inventories (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. A full inventory of NYSDOT-owned transportation infrastructure at risk to climate change hazards identified for NYS is essential.

2. Developing a digital data base of all NYSDOT "as built" structural and road bed elevations in coastal areas, at least to elevations up to 20 ft above current sea level is necessary to make reasonable decisions based on projected climate risks including SLR and storm surge.

F. Design Issues (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Sustainability and Climate Change Section)

1. Adaptation needs will evolve over time as climate science, impacts, technological advancements and adaptation strategies are further developed.

2. As available, State-endorsed climate change scenarios should be used, with updates of climate change scenarios taken into account if possible as they become available.

3. Design criteria should take into account the statistically non-stationary probabilities for hydrologic processes and other climate variables.

4. For some facility designs, such as road surfaces and bridge expansion joints, new heat thresholds may need to be considered.

5. Program and project designs should vary according to the expected schedule of implementation and according to the expected useful lifetime of the structure or project, because the appropriate design should be for the climate variables and impacts expected at the date of implementation and beyond.

6. Designs for rehabilitation and replacement should include climate adaptation planning, rather than being simply replacements of existing designs.

G. Infrastructure Adaptations (Engineering, Operations, Sustainability and Climate Change Section)

A range of infrastructure adaptations has been identified for NYSDOT purposes. Some of the principal ones are given here. (Institutional, policy and management adaptations are given above; see also NYSCAC, 2010, ch. 11.)

1. Sea Level Rise and Storm Surge

    a. Implement local flood proofing (sea walls) for State highways and other roads in the National Highway System

    b. Design road embankments, including bridge landings and approaches, as levees when possible and appropriate

    c. Elevate or relocate road systems and other critical systems to higher ground

    d. Design culverts and ditches for increased flooding

    e. Raise bridge landings and approaches

    f. Redesign to account for changes in scouring patterns

2. More intense precipitation

    a. Increase the carrying capacity of culverts, detention basins and other drainage systems to deal with potentially increased storm intensity

    b. Ensure adequate maintenance to achieve full design capacity

    c. Raise road embankments and strengthening slopes

    d. Raise or relocate roadways out of flood zones

    e. Monitor scour action at inland bridges and remediate as required

3. Heat hazards

    a. Reduce possible impacts on buildings and building materials

    b. Reduce impacts on road materials and bridge expansion (likely to be less significant)

4. Winter storms

a. Flexibility in potential reallocation of emergency resources

5. Winds

    a. Reconsider design wind speeds

    b. Monitor wind conditions at selected sites; obtain data from NOAA

H. Monitoring and assessment (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Monitoring and reassessment are critical components of any climate change adaptation plan; they relate both to the plan itself and to observed changes in climate and climate impacts. A wide range of elements for monitoring is presented in this report

2. Monitoring adaptation plans in the region should be done both to determine if they are meeting their intended objectives, for example to provide adequate drainage, and to discern any unforeseen consequences of the adaptation strategies

3. Monitoring of weather and climate including detailed site-specific climate impacts can often be done most effectively by personnel already on the ground

4. Monitoring of climate and detailed site-specific climate impacts can also be done effectively by automated and remote technologies, which should be regularly reassessed for applicability.

I. Training needs (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section, Workforce Learning and Development Bureau (Administration Division))

1. Training for staff for climate change adaptation will be a central part of NYSDOT's response. Such training can include the topics of:

    a. Climate science

    b. Future climate scenarios

    c. Changing guidelines for NYSDOT design, construction and operations,

    d. The overall framework of planning for climate change, including adaptation assessment steps.

e. Monitoring methods for site-specific climate impacts

2. Training can be in-person or through webinars and other electronic methods.

J. Communications (Administration, Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. There is a need for continued and enhanced engagement with professional organizations, local universities, and other state-wide adaptation initiatives, such as the Climate Action Council and the New York State Sea Level Rise Task Force

2 An appropriate role for NYSDOT includes providing relevant climate adaptation design criteria to local groups.

K. Research needs (Administration, Engineering, Policy and Planning, Sustainability and Climate Change Section)

1. A particular need is for research into how general climate change projections can be expressed in terms that engineers can use in designing transportation facilities. An example is the need for new design criteria for planning drainage systems in conditions of more intense precipitation.

2. Research is required into the best scope and methods for monitoring climate change impacts in NYS.

3. Mapping of areas at risk from sea level rise, storm surge, and inland flooding is a major need in order to identify transportation system vulnerabilities.

4. NYSDOT can make arrangements to ensure that updated climate information and scenarios are available on a regular basis.

A summary of the Divisions and other units that can take the lead in various categories of recommendations is provided in Table ES-1.

Table ES.1: Lead Roles by Categories of Recommendation

Category of Recommendations	Division or other unit							
	Comm. Office	Admin.	CC &EE	Eng.	Legal Affairs	Opera-tions	Policy & Plan.	Sustainability & CC Section
A. Planning policies and guidelines			X	X	X	X	X	X
B. Organization and management	X		X	X		X	X	X
C.Inter- and Intra-agency coordination	X	X	X	X	X	X	X	X
D. Regional aspects of adaptation planning			X	X		X	X	X
E. Vulnerability inventories			X	X		X	X	X
F. Design Issues			X	X				X
G. Infrastructure				X		X		X
H. Monitoring and Assessment of Adaptations			X	X		X	X	X
I. Training needs		X	X	X		X	X	X
J. Communications		X	X	X		X	X	X
K. Research needs		X		X			X	X

Chapter 1: Introduction

1.1 Introduction and goals This introduction and overview summarizes the goals and methods of the study, and lists the parts that follow this Introduction. The study has been funded by the NYSDOT through the University Transportation Research Center, Region II, with additional resources from Columbia University. The goal of the study, as given in the original RFP (UTRC, 2009, p. 1), is "to mainstream climate change adaptation strategies into every planned Departmental action, including legislation, policies, programs and projects in all areas and at all levels within the Department. Mainstreaming climate change strategies will ensure that assessment of climate change is an integral dimension of the design, implementation, monitoring and evaluation of policies, programs and projects in all program areas within the Department."

The objectives achieved by the study are to:

1. Review existing research literature on the implications of climate change for the transportation sector;

2. Synthesize existing knowledge base and analyze the implications by each program area of the Department;

3. Synthesize adaptation strategies by each program area within the Department; and

4. Disseminate findings to Department personnel and provide guidance for the purpose of effectively mainstreaming climate change adaptation strategies. (UTRC, 2009, p. 1)

1.2 Study methods The study relied on five key sources of information to review the principal issues relating to mainstreaming climate adaptation into the NYSDOT's operations. These are:

1. A literature review. For some aspects of climate change, there have already been substantial literature reviews, and these are taken into account. From the literature review carried out specifically for this project, additional references, including recent work, have been added to Chapters 2 and 3. The main results of the literature review carried out specifically for this project are presented in Chapter 4, dealing with adaptation strategies and best practices. The results of the literature review also impact Chapter 5, which contains the study recommendations, the results of discussion with key NYSDOT personnel, and related guidance on mainstreaming, and Chapter 6, dealing with communications and technology transfer.
2. Discussions with key NYSDOT personnel based on the Climate Risk Information Summary worksheet (Appendix 1). This worksheet was developed cooperatively by the project staff, the NYSDOT Technical Working Group (TWG), and Columbia's Advisory Working Group (AWG). The detailed results of

discussions with NYSDOT personnel on climate risk, based on the Climate Risk Information Summary, are in Chapter 4.

3. Advice and guidance from the NYSDOT's Technical Working Group for the Project. The members of this group are identified in Appendix 3; their advice has benefited the entire report.
4. Advice and guidance from Columbia's Advisory Working Group for the Project. The members of this group are identified in Appendix 3; their advice has also benefited the entire report.
5. Information from Columbia's many ongoing and completed projects in climate change adaptation, especially those in the NY region. These are referenced throughout the report.

1.3 Report contents This report summarizes this information and provides recommendations for the NYSDOT based on it. Following this introduction, which is Chapter 1, there are 5 additional chapters and 3 appendices, described here.

Chapter 2: Climate Change, Transportation in New York State, and the Mission of the New York State Department of Transportation. This chapter includes a summary of recent scientific views of climate change globally and describes the most recent available scenarios of temperature, sea level rise, precipitation and extreme events for New York State. Then, a summary of the transportation network in New York State is provided, and the mission and organization of the NYSDOT from official sources is given. The material in this chapter provides the background for the following chapters.

Chapter 3: Climate Change Impacts, Vulnerabilities, and Transportation in New York State. This chapter describes the principal climate changes that will affect transportation in New York State: higher sea levels, storm surge, higher temperatures, and changing precipitation patterns. The vulnerabilities in transportation systems that result from these climate changes are described in detail by climate variable. Then, some regional differences in impacts and vulnerabilities are given.

Chapter 4: Adaptation Strategies and Best Practices. In this chapter, the main adaptation strategies and best practices for climate change risk management are given as they relate to the NYSDOT's mission. An overview and key findings of the literature review carried out for this study are given; then descriptions of the most significant adaptation options for NYSDOT for different climate impacts are provided.

Chapter 5: Mainstreaming Climate Change Adaptation Strategies into the NYSDOT's Actions, Including Legislation, Policies, Programs and Projects. This chapter provides a range of potential adaptation strategies for mainstreaming climate change into the NYSDOT's operations and infrastructure investment, including summary table of recommendations. These recommendations are based on the literature review, the climate risk information discussions, the researchers' experience with adaptation in the New York region and elsewhere, and the advice of the advisory groups. The chapter also presents the detailed results of discussions with NYSDOT personnel on climate risk, based on the Climate Risk Information Summary. These include mainstreaming

information and insights for 2 Divisions, 12 Offices, and 1 Region of NYSDOT. Adaptation strategies are further discussed in terms of organization and training guidelines, planning documents and effective adaptation; linkages to capital and rehabilitation cycles; and keeping current with climate science and adaptation planning methods.

Chapter 6: Communications and Technology Transfer Plan. This chapter provides an outline for a workshop for senior managers, discusses other potential workshops, and describes potential webcasts and websites for the NYSDOT.

These chapters are followed by 3 Appendices:

Appendix 1: Climate Risk Information Summary;

Appendix 2: Literature Review Methodology;

Appendix 3: Advisory Group Members.

The Appendices are followed by references and a list of acronyms used in the report.

Chapter 2: Climate Change, Transportation in New York State, and the Mission of the New York State Department of Transportation

2.1 Introduction It is now widely recognized that global average temperatures and sea levels have been increasing for the last century and have been accompanied by other changes in the Earth's climate. As these trends continue, climate change is increasingly being recognized as a major global concern. The Intergovernmental Panel on Climate Change (IPCC), was formed in 1988 by the World Meteorological Organization and the United Nations Environment Programme to provide objective information regarding the changing climate. The work of the IPCC, presented in its periodic reports, is undertaken by an international group of hundreds of climate scientists and other experts.

In its most recent report, the Fourth Assessment Report (IPCC, 2007), it is reported that there is a greater than 90 percent chance that rising global average temperatures, observed since 1750, are primarily due to human activities. The principal driver of climate change over the past century has been increasing levels of atmospheric greenhouse gases associated with fossil fuel combustion, changing land use practices and other human activities. Atmospheric concentrations of carbon dioxide, the major greenhouse gas, are now more than one-third higher than in pre-industrial times. Concentrations of other important greenhouse gases, including methane, ozone and nitrous oxide have increased as well (Trenberth et al., 2007).

In significant part as a result of the work of the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC), efforts to mitigate the severity of climate change by limiting levels of greenhouse gas emissions are underway globally. As important as these efforts are and will continue to be, impacts from climate change are inevitable, due in part to warming attributed to greenhouse gas forcing mechanisms that already influence climate processes, some of which occur over a long period of time. Responses to climate change have therefore gone beyond a focus on mitigation to include adaptation measures in an effort to minimize the impacts of climate change already underway and to prepare for unavoidable future impacts (Horton et al., 2011).

2.2 Climate change and New York State An overview of what is known about climate change in New York State is provided here. The most recent work is Rosenzweig et al., 2011; earlier work includes Rosenzweig and Solecki, eds., 2001 and NPCC 2010. The ClimAID study defined 7 climate regions for NYS; these are shown in Figure 2.1.

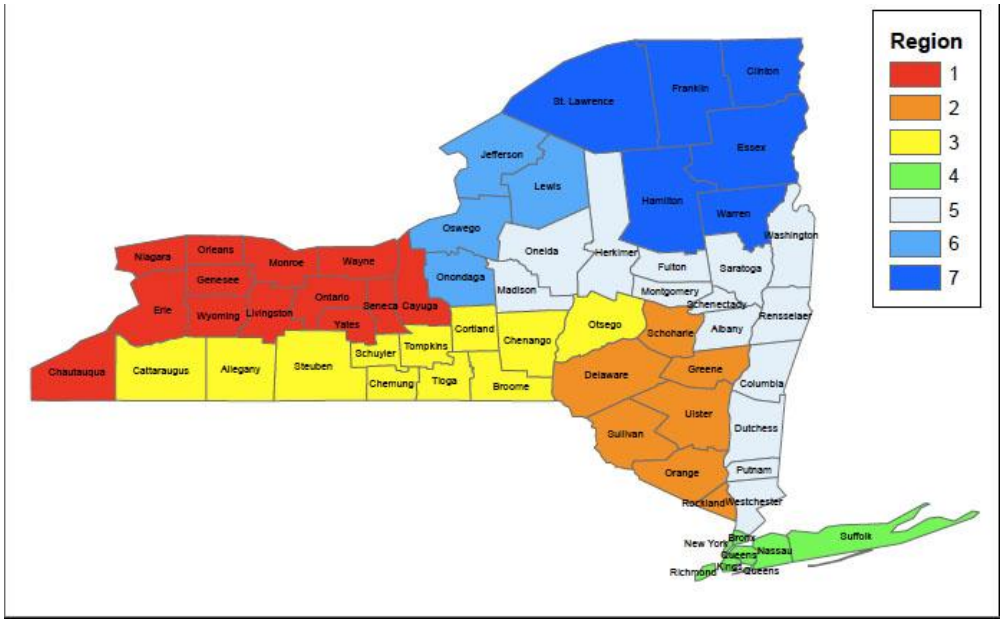

Figure 2.1 ClimAID climate regions of New York State Source: Horton et al., 2011. Note: 1 = Western New York, Great Lakes Plain; 2 = Catskill Mountains and West Hudson River Valley; 3 = Southern Tier; 4 = New York City and Long Island; 5 = East Hudson and Mohawk River Valleys; 6 = Tug Hill Plateau; 7 = Adirondack Mountains

2.2.1 Current climate

Average Temperature and Precipitation

New York State's climate can be described as humid continental. The average annual temperature varies from about 40°F in the Adirondacks to about 55°F in the New York City metropolitan area. The wettest parts of the state—including parts of the Adirondacks and Catskills, the Tug Hill Plateau and portions of the New York City metropolitan area—average approximately 50 inches of precipitation per year. Parts of western New York are among the state's driest, averaging about 30 inches of precipitation per year. In all climate regions, precipitation is relatively consistent in all seasons, although droughts and floods are not uncommon. These precipitation figures include snow; in New York City, 1 inch of rain equals about 11 inches of snow; this ratio varies throughout the state and ranges up to 1: 16 in Buffalo.

Sea-level Rise

Prior to the Industrial Revolution, sea level had been rising along the East Coast of the United States at rates of 0.34 to 0.43 inches per decade (Gehrels, et al., 2005; Donnelly et al., 2004), primarily because of regional subsidence (sinking) in coastal areas as the Earth's crust still slowly re-adjusts to the melting of the ice sheets since the end of the last ice age. Within the past 100 to 150 years, regional sea level has been rising more rapidly than over the last thousand years (Holgate and Woodworth, 2004). Currently, rates of sea-level rise on New York State's coastlines are between 0.86 and 1.5 inches per decade, averaging 1.2 inches per decade since 1900. Sea-level rise rates, measured by tide gauges, include both the effects of global warming since the onset of the Industrial

Revolution and the residual crustal adjustments to the melting of the ice sheets. Most of the observed current climate-related rise in sea level over the past century can be attributed to expansion of the oceans as they warm, although current and future melting of glaciers and ice sheets may become the dominant contributor to sea level rise during this century (Church et al., 2008).

Snowfall

With the exception of the coastal area, New York State averages more than 40 inches per year of snow (http://nysc.eas.cornell.edu/climate_of_ny.html). Snowfall varies regionally, based on topography and the proximity to large lakes and the Atlantic Ocean. Maximum seasonal snowfall is more than 175 inches in parts of the Adirondacks and Tug Hill Plateau, as well as in the western parts of the state. The warming influence of the Atlantic keeps snow in the New York metropolitan region and Long Island below 36 inches per year. Heavy snow squalls frequently occur near the Great Lakes, generating as much as 48 inches of snow in a single storm. In southern parts of the state, snowfall amounts occasionally exceed 20 inches during nor'easters. New York City, for example, experiences snow storms that exceed 20 inches about once every 30 years (New York State Climate Office, 2003).

2.2.2 Future scenarios for sea level rise, temperature and precipitation

2.2.2.1 Sea Level Rise

Scenarios for sea level rise for New York City are available from NPCC (2010, App. A). Updated scenarios for the entire NYS coastal area are given in Horton et al., forthcoming. These are based on two procedures. The first uses the IPCC methods of estimating sea level rise, which take into account global as well as local changes. The second modifies the IPCC procedures to take into account estimated more rapid ice melt. The results are shown in Table 2.1. For the IPCC methods, sea level rise in the coastal areas of NYS is likely to increase by 8 to 23 inches by the 2080s; for the rapid ice melt scenario, the range is 37 to 55 inches. This information, and that for temperature, precipitation, and extreme events, below, will provide essential inputs to planning and design as climate change adaptation in the NYSDOT moves forward.

Table 2.1: Sea level rise projections for New York State

	2020s	2050s	2080s
Sea level rise (SLR)	+1 to 5 in	+ 5 to 12 in	+ 8 to 23 in
SLR with Rapid ice-melt	+ 4 to 10 in	+ 17 to 29 in	+ 37 to 55 in

Source: Horton et al., 2011

Table 2.1 shows the central range (middle 67% of values from model-based probabilities) across 7 GCMs and 3 GHG emissions scenarios. Sea level rise is rounded to the nearest inch. The "rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimatic studies. For a detailed description of methods, see NPCC (2010), App. A.

2.2.2.2 Changes in Temperature and Precipitation

Scenarios for temperature and precipitation changes in the 7 climate regions of NYS are available from Horton et al., 2011. These are shown in Table 2.2. The figures shown are the central range (middle 67%) of values from 48 scenarios (16 GCMs, 3 emissions scenarios). Overall, temperature increases in the 2080s across the regions range from a low of 4^{o} F to a high of 9^{o} F. Changes in annual precipitation for the 2080s across the regions range from a low of 0% to a high of 15% as compared to the baseline. The table indicates the stations that were used for each region; baseline values are the averages of annual temperature and precipitation from these stations. These model-based scenarios are important to planning, but they do understate the total range of uncertainty involved in climate change, which argues for additional concern with robustness in adaptation.

Table 2.2: Temperature and Annual Precipitation Scenarios for the 7 Climate Regions of New York State. Source: Horton et al., 2011. (For region names, see key to Figure 2.1.)

Region 1	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	48° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.5 to 8.5° F
Precipitation Central Range	37 in	0 to +5 %	0 to +10 %	0 to 15 %

Stations used for Climate Region 1 are Buffalo, Rochester, Geneva, and Fredonia.

Region 2	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	48° F	+1.5 to 3.0° F	+3.0 to 5.0° F	+4.0 to 8.0° F
Precipitation Central Range	48 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for region 2 are Mohonk Lake, Port Jervis, and Walton.

Region 3	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	46° F	2.0 to 3.0° F	+3.5 to 5.5° F	+4.5 to 8.5° F
Precipitation Central Range	38 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for region 3 are Elmira, Cooperstown, and Binghamton.

Region 4	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	53° F	+1.5 to 3.0° F	+3.0 to 5.0° F	+4.0 to 7.5° F
Precipitation Central Range	47 in	0 to +5 %	0 to +10 %	+5 to 10 %

Stations used for Region 4 are New York City (Central Park and LaGuardia Airport), Riverhead, and Bridgehampton.

Region 5	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	50° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.0 to 8.0° F
Precipitation Central Range	51 in	0 to +5 %	0 to +5 %	+5 to 10 %

Stations used for Region 5 are Utica, Yorktown Heights, Saratoga Springs, and the Hudson Correctional Facility.

Region 6	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	44° F	+1.5 to 3.0° F	+ 3.5 to 5.5° F	+4.5 to 9.0° F
Precipitation Central Range	51 in	0 to +5 %	0 to +10 %	+5 to 15 %

Stations used for Region 6 are Boonville and Watertown.

Region 7	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central Range[2]	42° F	+1.5 to 3.0° F	+3.0 to 5.5° F	+4.0 to 9.0° F
Precipitation Central Range	39 in	0 to +5 %	0 to +5 %	+5 to 15 %

Stations used for Region 7 are Wanakena, Indian Lake, and Peru.

While the scenarios for the different climate regions are naturally relatively close because of the geography of the state, there are differences that may be reflected in NYSDOT programs and policies. These recent forecasts can be seen within the context of previous forecasts for the New York area, dating back to 1999, as shown in Table 2.3, based on

fewer GCMs and earlier versions of the GCMs that were used; it can be expected that as NYSDOT continues and enhances its climate change adaptation efforts over the years, scenarios will be continually improved because of model improvements.

Report Title	Year	Organization	Temperature	Precipitation	Sea Level Rise	Notes
Hot Nights in the City: Global Warming, Sea-Level Rise, and the New York Metropolitan Region	1999	Environmental Defense Fund	2050s: 4.0°F to 5.0°F 2080s: 6.0°F to 10.0°F	2050s: -5% to 15% 2080s: 0% to 30%	2050s: 7 to 17 in 2080s: 12 to 36 in	Uses 2 GCMs Aerosol and non-aerosol scenarios Temperature projections are reduced when including aerosols
Climate Change and a Global City: The Potential Consequences of Climate Variability and Change	2001	U.S. National Assessment & Columbia Earth Institute	2020s: 1.5°F to 3.5°F 2050s: 2.5°F to 6.5°F 2080s: 4.5°F to 10.0°F	2020s: 0% to 10% 2050s: -15% to 15% 2080s: 0% to 30%	2020s: 4 to 11 in 2050s: 9 to 24 in 2080s: 12 to 36 in	Uses 2 GCMs Aerosol and non-aerosol scenarios Report contains sea level rise projections for Long Island
Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions	2007	Union of Concerned Scientists	2020s: 2.5°F to 2.5°F 2050s: 4.0°F to 6.0°F 2080s: 5.0°F to 10.0°F	2020s: N/A 2050s: N/A 2080s: 10%	2050s: 3 to 13 in 2080s: 4 to 33 in	Uses 4 GCMs and 2 emissions scenarios Focused on 7 cities in the Northeast - projections are for the entire Northeast
NYC DEP Climate Change Program Assessment and Action Plan	2008	New York City Department of Environment Protection	2020s: 1.5°F to 3.0°F 2050s: 2.0°F to 5.5°F	2020s: -5% to 5% 2050s: 0% to 10% 2080s: 5% to 15%	2020s: 2 to 5 in 2050s: 7 to 12 in 2080s: 12 to 20 in	Uses 5 GCMs and 3 emissions scenarios

Table 2.3: Previous climate scenarios for the NY region (based on the documents cited). Precipitation scenarios are for annual precipitation.

2.2.3. Future scenarios for extreme events

Mean values for the elements of climate scenarios are important for many adaptations, such as defenses against rising sea levels. In addition, extreme values are also important in adaptation planning, as for example in flooding. There is less information in climate scenarios in general about climate extremes than climate means; however, some valuable information is available on which to develop scenarios for extremes. This section describes the main extreme events of interest, and provides some quantitative information from Horton et al., 2011. A table of extreme events for New York City is in NPCC, 2010, App. A. Because models provide relatively less information on extreme events than on means, detailed on-the-ground observations over time will be very important inputs to adaptation planning.

2.2.3.1 Extreme Temperatures and Heat Waves

Extreme hot days and heat waves can be defined in several ways to reflect the diversity of conditions experienced across New York State. Among the definitions in use are individual days with maximum temperatures at or above: 85°F, 90°F, and 95°F (Horton et al., 2011). Heat waves can be defined as three consecutive days with maximum temperatures above 90°F. Due to regional variations in the NYS's climate, no single extreme event metric will necessarily be appropriate for adaptation planning for the entire state. In the cooler northern parts of the state defining hot days with a lower temperature threshold may be more appropriate whereas in the warmer, southern regions, higher temperatures may be used.

Extreme cold days can also be defined to reflect the state's regional climate variations: Individual days with minimum temperatures at or below 32° F or below 0° F.

Days with minimum temperatures below 0° F may be an appropriate measure for northern parts of the state, while days with higher temperatures may be useful for locations closer to the coast, where maritime air from the Atlantic Ocean moderates temperatures.

In all locations, the number of extreme events from year-to-year is highly variable. For example, in 2002, Port Jervis experienced temperatures of 90˚F or higher on 31 different days; in 2004 days with temperatures of 90˚F or higher only occurred four times (Horton et al., 2011).

2.2.3.2 Extreme Precipitation and Flooding

Throughout New York State, heavy rainfall can lead to flooding in all seasons. In much of Central and northern New York State, flooding is most frequent in spring, when rains and rapid snowmelt lead to runoff. Ice jams sometimes contribute to serious flooding in localized areas during spring and winter as well. Farther south, floods are more frequent during the summer. Urbanized areas (due to impermeable surfaces, including roads and buildings), steep slopes and low-lying areas are particularly vulnerable.

Across the state, the weather mechanisms responsible for producing heavy rainfall vary and are generally more common near the coasts. Intense precipitation can be associated with small-scale thunderstorms, most common in the warmer months. Large-scale storms including cold/cool-season nor'easters (which can produce snow and ice in addition to rain) and warm-season hurricanes can also produce intense precipitation (Horton et al., 2011).

Another extreme precipitation event experienced in regions of New York State is lake-enhanced snow. These snowfall events, which can last anywhere from an hour to a few days, affect places downwind of the lakes in Upstate New York. Parts of western New York (including Buffalo, NYSDOT Region 5) receive snowfall from Lake Erie. The Tug Hill region located between the Adirondacks and Lake Ontario (NYSDOT Regions 2, 3, 7) experiences snowfall from Lake Ontario. Lake-enhanced snowfall is highly localized;

for example, an October 2006 lake-effect snow event produced as much as 2 feet of snow in parts of the Buffalo metropolitan area, while just 20 miles away, Niagara Falls received approximately an inch of snow (Hamilton et. al 2007).

Over the past several decades, the state and the surrounding region have experienced a trend toward more extreme precipitation events (Hayhoe et al. 2007, Groisman et al. 2004). The increase in more frequent heavy rainfall events is consistent with the trend for the United States as a whole, which, in the past 50 years, has seen the greatest increase in the Northeast (USGCRP, 2009). As with extreme temperatures, year-to-year variations in extreme precipitation events are large. Because extreme precipitation events tend to occur relatively infrequently, long time series are needed to identify trends.

2.2.3.3 High winds, lightning strikes, hail and freezing rain.

High winds, lightning strikes, hail are common during severe thunderstorms; they tend to effect small areas. Freezing rain events are less common but can affect larger areas. The relationship of climate change to the number and intensity of these storms is not yet clearly understood, and the role of detailed on-the-ground observations over time will be important to adaptation planning..

2.2.3.4 Coastal Storms

The two types of storms with the largest impact on the state are hurricanes and nor'easters. Hurricanes strike New York State very infrequently, generally between July and October, and can produce large storm surges along the coast and cause wind damage and intense precipitation inland. Nor'easters are far more frequent and of longer duration; they generally do not occur during the warmest months. Nor'easters are usually associated with smaller surges and weaker winds along the coast than hurricanes. However, because of the their extended periods of high winds and high water, the flooding impacts of nor'easters can be significant, in particular because the storms will extend over one or more periods of high tide, adding to surge height.

Recent quantitative estimates of extreme climate events in NYS include NPCC (2010, App. A), and Horton et al. (2011), which provides scenarios for extreme events for the 7 regions of NYS. The table of climate extremes for Climate Region 2 is reproduced here as Table 2.4.

2.3 Transportation in New York State This section provides: an overview of the NYS transportation system including all sectors; the organization and mission of the NYSDOT; and a brief description of other relevant agencies.

New York State's transportation system, as described in NYSDOT's website (www.nysdot.gov), includes "A state and local highway system that annually handles over 130 billion vehicle miles. This total system encompasses more than 113,000 highway miles and more than 17,400 bridges"

Table 2.4: Scenarios for extreme events for Climate Region 2, Catskill Mountains and West Hudson River Valley (Source: Horton et al., 2011).

	Extreme Event	Baseline	2020s	2050s	2080s
Heat waves & Cold Events	# of days per year with max temperature at or above:				
	90°F	12	13 (14 to 24) 34	16 (22 to 40) 53	21 (28 to 65) 75
	95°F	2	2 (2 to 5) 10	3 (5 to 12) 20	4 (7 to 28) 39
	# of heat waves per year	2	2 (2 to 3) 5	2 (3 to 5) 7	3 (4 to 9) 10
	average duration	4	4 (4 to 5) 5	5 (5 to5) 6	5 (5 to 6) 8
	# of days per year with min temperature at or below 32°F	138	101 (111 to 121) 128	70 (91 to 111) 115	57 (70 to 101) 112
Intense Precipitation	Number of days per year with rainfall exceeding:				
	1 inches	12	10 (11 to 13) 14	10 (12 to 14) 14	10 (12 to 14) 15
	2 inches	2	1 (2 to 2) 3	1 (2 to 3) 3	1 (2 to 3) 3

Region 2 – (Port Jervis Station) Note: Heat waves are defined as 3 or more consecutive days with maximum temperature exceeding 90° F.

Further elements in the system are given in the NYSDOT's most recent Capital Plan (NYSDOT, 2009):,

- Approximately 2.6 billion passenger trips provided by more than 130 public transportation operators (including the Metropolitan Transportation Authority -

MTA) throughout the State, accounting for one out of every three public transportation riders in the nation;

- Approximately 88 million passengers who travel through more than 500 public and private aviation facilities within the State;
- Approximately 1.5 million riders each year who use Amtrak's Empire and Adirondack services, and more than 8 million rail passengers who pass through Penn Station using Amtrak's Northeast Corridor;
- More than 150 million tons of freight that pass through five port authorities (the Port Authority of New York and New Jersey, Albany Port District Commission, Port of Oswego Authority, Ogdensburg Bridge & Port Authority and the Port of Buffalo and numerous private ports handling; and
- More than 75 million tons of freight that move across 3,500 miles of rail." (NYSDOT 2009, p. 3)

2.3.1 Mission and Organization of the NYSDOT

The NYSDOT is responsible under Section 10 of the State Transportation Law for planning a balanced statewide transportation system. The Department's capital program traditionally includes financing to support the State highway system; State and local bridges; capital needs of public transportation systems with exceptions such as the MTA and the New York State Thruway Authority; and pass-through funding for passenger and freight rail, port and aviation capital projects. In addition to capital projects, the NYSDOT program includes funding to support the Department's operations (including preventive maintenance, safety and traffic management and mobility), as well as engineering and program administration to successfully deliver and to manage the various components of the capital program. The NYSDOT program, however, does not include the capital needs of the MTA, New York State Thruway Authority or New York State Bridge Authority. (NYSDOT October 2009, p. 9)

The NYSDOT owns, designs, operates and maintains the majority of the Interstate and State Highway system in NYS. Along with Interstate, State and local highway miles in NYS there are associated bridges, ramps, underpasses, drainage systems, other related structures (including about one million culverts on State and local roads), and signage and signal systems. The NYSDOT also inspects all bridges not owned by other authorities, has multimodal relationships with ports, Amtrak, and other agencies, and is a voting member of the thirteen Metropolitan Planning Organizations (MPOs) throughout NYS. Although its immediate concerns are concentrated on roads and bridges it owns, the NYSDOT is connected in a wide variety of ways to transportation systems throughout the state that use or otherwise interact with the facilities they manage. NYS also owns Republic and Stewart airports, and these are operated by lessees under the supervision of the NYSDOT.

The NYSDOT is organized into 8 divisions under the Commissioner. These are Administrative Services; Audit and Civil Rights; Engineering; Information Technology; Legal Affairs; Operations; Policy and Planning; and Office of the Commissioner. The NYSDOT has 11 regional offices (Figure 2.2) in addition to the Main Office in Albany;

each of the regions has an organizational structure similar to the main office structure. Of these 8 divisions, the two largest in terms of employees across the NYSDOT (including the regions) are Operations, with 5,383 employees as of the beginning of 2011, and Engineering, with 2,980 employees, out of a total NYSDOT employment of 9,258. The NYSDOT's capital programs for Fiscal 2010-2011 and 2011-2012, a good measure of the size of the agency's activities, are $3.5 billion for the fiscal years beginning April 1.

In addition to its central operations and maintenance work, the NYSDOT also has responsibility for large capital projects, including its role as joint lead with the New York State Thruway Authority and the MTA Metro North Railway in studying possible replacements for the Tappan Zee Bridge. Further, the NYSDOT has undertaken projects on a fast-track basis to deal with emergencies. The Lake Champlain Bridge which spanned the state line between Crown Point, New York and Chimney Point, Vermont was deemed unsafe and was closed and demolished, and a project to replace this bridge is underway by the NYSDOT and the Vermont Agency of Transportation (VTrans) as co-lead agencies under an agreement between the states. This bridge is essential to local populations and businesses.

In the area of climate change and energy use, the NYSDOT has formed the Sustainability and Climate Change Section in addition to the Climate Change and Energy Efficiency (CC & EE) Team, which will play the key role in mainstreaming climate change adaptation into the NYSDOT's operations and investments, and has also initiated the Sustainability and Climate Change Section in the Policy and Planning Division.

2.3.2 Other agencies.

There are many other large and small agencies in NYS that deal with aspects of the State's transportation network.

- The NYS Thruway Authority (NYSTA) operates the toll-collecting thruway and related bridges connecting New York City via Albany and Rochester to Buffalo (it also operates the state's canals) (http://www.nysthruway.gov/.).

Figure 2.2 Map of NYSDOT Regions. Source: NYSDOT

- The Metropolitan Transportation Authority (MTA) is the largest transit operator in the nation, selling 8.5 Million passenger trips per day (http://www.mta.info/sustainability/pdf/synopsis.pdf). MTA includes the following operating agencies: New York City Transit, Metro North Railroad, Long Island Railroad, MTA Bridges and Tunnels, MTA Long Island Bus, MTA Bus Company, and MTA Capital Construction (http://www.mta.info/). The MTA has been active in considering climate change mitigation and adaptation, (MTA, 2007, MTA, n.d.; (www.mta.info/.../pdf/Jacob_et%20al_MTA_Adaptation_Final_0309.pdf) although this work has been constrained by recent budget problems.

- The Port Authority of New York and New Jersey (PANYNJ) owns and operates international and domestic airports and marine ports, and interstate ground transportation facilities serving NY and NJ. The agency's airports, bridges, tunnels, bus terminals, the Port Authority Trans Hudson Corporation (PATH) rail system, AirTrain services, and seaports move both cargo and nearly 1 Million people each day. The Port of New York and New Jersey is the third largest port facility in North America, and the largest facility on the East Coast. In 2008 the port handled over 55 million metric tons of bulk imports and exports (http://www.panynj.gov/port/). The PANYNJ has been concerned with climate change largely in the context of air quality and mitigation (http://www.panynj.gov/about/climate-change-air-quality.html)

- Other agencies that operate transit facilities in the State are Amtrak, freight railroads, the City of New York (Staten Island Ferry and some bridges); NJ Transit (bringing commuters from NJ to Pennsylvania Station and bus terminals; the Ports of Buffalo and Albany, and a variety of other local and private transportation companies and agencies (Jacob et al., 2011).

- Bridge authorities include the New York State Bridge Authority, Ogdensburg Bridge and Port Authority, Peace Bridge Authority, and Thousand Island Bridge Authority.

Chapter 3: Climate Change Impacts and Vulnerabilities of the Transportation System in New York State

3.1 Introduction In this chapter, the range of expected impacts on transportation (such as coastal and inland flooding, heat stress on materials, drainage impacts of intense precipitation, and others) is identified based on current scientific knowledge, literature review, and existing case studies. The principal climate vulnerabilities that will affect transportation in New York State will result from higher sea levels, storm surge, higher temperatures, and changing precipitation patterns. Higher sea levels and associated higher storm surges will be associated with NYSDOT regions 8, 10, 11 and 1 (climate regions 4 and the southern parts of regions 2 and 5; Westchester County is a coastal county, and sea level rise will impact counties along the Hudson River up to Troy). Higher temperatures will impact all regions, and changing precipitation patterns will also impact all regions (NYSERDA ClimAID Team, 2011), All modes of transportation in NYS, including some of those under the jurisdiction of the NYSDOT, are at risk from these climate variables. Table 3.1 (derived from Horton et al., 2010; NRC, 2008, 2010; Zimmerman and Faris, 2010; and Jacob et al., 2011) provides a summary of sector-specific impacts of climate change for the transportation sector.

3.2 Vulnerabilities and impacts on the NYS transportation system by climate variable This section describes vulnerabilities and impacts that present challenges to transportation in NYS, especially as they relate to the NYSDOT's mission, based on literature review, interviews/discussions with NYSDOT personnel, and existing case studies. A full exposition of vulnerabilities and adaptation options for land, marine, and air transport is provided in the Annexes to Chapter 5 of NRC, 2008, and a full listing for NYS is in Jacob et al. (2011).

3.2.1 Vulnerabilities and impacts from sea level rise and storm surge

Sea level rise, which may be as much as one meter (1 m = 39.37") by the end of the 21st century, will affect many transportation systems in New York State (NPCC 2010, App. A; Horton et al., 2011). There are two principal effects of higher sea levels. Sea level rise will cause permanent inundation of low-lying lands, and higher sea levels will increase the frequency and severity of coastal flooding. Storm-surge hazards along New York's shores (and the tidal Hudson River from the New York Harbor to the Federal Dam at Troy) arise primarily from tropical cyclones (hurricanes, tropical storms, tropical depressions) during the summer and fall, and from extra-tropical winter storms (nor'easters) during the winter and early spring. In New York, a substantial number of transportation systems are located along the water at low elevations and some subways, railroads and highways are in tunnels below sea level. Even if storms do not become more intense, flooding will increase significantly because storms will occur at higher sea levels. For example, for flooding now occurring once every 100 years, many transportation systems are at risk already; sea level rise will increase the probability of flooding dramatically. Forecasts imply that the storm elevations now reached by the 100-year flood (i.e., a 1-percent annual probability of occurrence) will be reached before the

end of the century by a flood with an approximately 3 to 10 percent annual probability of occurrence—about a three- to ten-fold increase (NPCC, 2010, App. A).

3.2.2 Vulnerability and impacts from Increased Temperatures and Heat Waves

Increases in both annual average temperatures and the number of days per year with extreme high temperatures will affect NYS transportation systems in many ways. Because of the potential destructive effects of higher temperatures, air conditioning requirements for rolling stock and stations and ventilation requirements for tunnels will increase (Jacob et al., 2011; Zimmerman and Faris, 2010). At present, transportation infrastructure in New York State is generally engineered to perform according to the historic record of temperatures. However, as the temperatures in New York State rise, new heat thresholds may need to be considered. Among the issues that may be addressed as the result of higher temperatures are expansion joint design for bridges, rail design to avoid buckling, and heat degradation of road surface and other materials. HVAC requirements may include public health considerations such as extended waits on train platforms or service in toll booths (Clarke 2002). An example of climate adaptation to current conditions that suggests the type of adaptation that will be required in the future is found in the London Underground. Certain sections of this system are fitted with forced air pressure ventilation systems that operate automatically when temperature and humidity thresholds are reached (Clarke 2002, p.158).

3.2.3 Vulnerabilities and Impacts from Increased Intense Precipitation

Increases in intense precipitation events, which are thought to be likely (NPCC, 2010, App. A), will result in increased urban and inland flooding. As one indicator, the number of days per year with extreme precipitation (e.g., more than 2 inches per day) is likely to increase. Increases in intense precipitation will have serious implications not only for roadways near rivers, lakes and other inland water bodies, but also for the State's bridges and culverts. Impacts from increased intense precipitation will include flooded roadways, increased potholes in pavement, damaged bridges and washed out culverts (Meyer, 2008). These factors would result in challenges such as delays in emergency services, increased need for pumping and an increased strain on capital budgets. Design changes that will be needed to meet these challenges may be extensive for drainage and other systems and required also for adjustments to changing scouring potentials for bridge foundations of some rivers.

Table 3.1 Transportation Sector Impacts

(Sources: NRC 2008; 2010; Zimmerman and Faris, 2010; Jacob et al., 2011)

Temperature, Heat waves & Cold Events	Hotter summers would • impact pavements and materials • place strain on equipment and machinery, increasing the need for maintenance and reducing lifetimes • result in expansion of heat sensitive equipment • increase the need for cooling of machinery • deteriorate road infrastructure from buckling and expansion • warmer summers and shorter winters would provide more time for transportation maintenance and construction work More frequent and intense heat waves, and hot summer days would • increase energy demand, resulting in more frequent power outages leading to transportation closures and delays • result in fluctuations in voltage, damaging equipment and interrupting service • increase heat levels of equipment In some areas, warmer winter temperatures may raise the chances of freeze/melt cycles and increase the need for morewidespread sp heave damage to road surfaces
Precipitation, Intense Precipitation & Droughts	Increased average annual precipitation would • place strain on equipment and machinery, increasing the need for maintenance and reduce lifetimes • require heavier use of pumps • lead to more Combined Sewer Overflow (CSO) events, polluting coastal waterways and potentially impacting water transportation and associated infrastructure More frequent intense rainfall would • impact culverts, bridges, and approaches to bridges • lead to more flooding of transportation facilities, requiring heavier use of pumps • increase transportation delays and cause more wear and tear on equipment and infrastructure • increase construction and repair schedule delays • increase emergency management requirements More frequent and intense drought would place strain on some equipment and materials
Sea Level Rise, Coastal Floods & Storms	Higher average sea levels would • increase issues of bridge scour in coastal zones. • increase salt water encroachment resulting in increased damage to infrastructure not manufactured to withstand saltwater exposure • decrease clearance levels under some bridges • increase flooding of low-lying roadways and other transit More frequent and intense coastal flooding would • result in more frequent damages to and outages of roadways and other transportation infrastructure in coastal areas • increase frequency of use of emergency management actions • lead to structural damage to infrastructure due to wave action

3.2.4 Vulnerabilities from Increased Coastal Storm Intensities

While it is not known whether the total number of coastal storms (hurricanes, nor'easters) will significantly change, it is considered likely that their intensity will increase (NPCC 2010). This more intense precipitation will cause more frequent coastal flooding and impacts such as road closures and damages. High winds may also result in more frequent temporary closures or restricted use of larger bridges. (The increase in coastal storm intensity will affect other modes as well, including air, rail, and marine transportation systems.)

3.2.5 Vulnerability to Ice and Snow Storms

The central and northern regions of New York (with elevations that exceed 5,000 feet) are subject to more frequent and severe ice and snowstorms than downstate regions. Road (and other) transportation systems and operations are quite susceptible to freezing rain (icing) and snow. In fact, New York State is the most vulnerable to icing of all states in the lower 48 (Klaus Jacob, personal communication). Icing is a hazard for vehicular traffic that requires emergency actions by the NYSDOT and other jurisdictions. Indirectly, icing can also affect transportation by loss of electric power and/or, to a lesser degree, communication systems.

Freezing rain, black-ice conditions and severe snow pose hazards to highway transportation now. Climate change is likely to bring changes to these hazards with different trends in different parts of New York State. For instance, whether the lake effect, which brings severe snow to Buffalo and other portions of western New York (NYSDOT Region 5), will increase or not is uncertain, but it is a possible climate change scenario. On the one hand, increasing winter temperatures are likely to shorten the ice cover of the Great Lakes and, therefore, potentially allow more moisture to be drawn from the ice-free lakes, which would then fall as snow in western New York. However, by the end of the century warmer winter temperatures may no longer support frozen precipitation (Kunkel et al., 2002). Climate monitoring for such trends will be an important element in climate change adaptation.

While the severity of such extreme snowfalls is likely to increase, the number of days per year with snow on the ground is likely to decrease. In downstate regions (and especially coastal areas), nor'easters that in the past caused blizzards will more often turn into severe rainstorms. On the benefit side, it is likely that the need for snow removal and salting of highways will gradually decrease for low-elevation, downstate and coastal areas. The need for snow removal and salting under future climate conditions may change little in upstate New York, though it may increase in western New York in areas that are subject to episodes of extreme winter lake effects.

3.2.6 Vulnerabilities to and Benefits from Other Climate Processes

Transportation systems in New York are most at risk from heat, extreme precipitation and freezing rain events and coastal storm surges in combination with sea level rise. Other

climate hazards, such as extended droughts and water shortages, can also impact the functioning and performance of the transportation system. Two potential benefits from rising temperatures are a longer road repair season, and a lengthening of the Great Lakes shipping season (Jacob et al., 2011).

3.3 Regional aspects of vulnerabilities There are many regional elements of climate change impacts and vulnerability in NYS, and thus there will have to be to some extent varying adaptation programs in the regions of the NYSDOT. The most important example is the impact of rising sea levels and associated higher storm surges on transportation systems in NYSDOT Regions 8. 10, 11 and 1 (climate region 4 and the lower parts of climate regions 2 and 5). There will also be differences in heat and intense storm impacts among regions, with higher heat impacts in lower and more southerly areas, and drainage problems from intense flooding in more urbanized areas.

For example, in the Buffalo area (NYSDOT Region 5), because of the conditions noted above, such as "lake effect" snow, higher intensity of winter snow and ice operations may be required; this will require more resources for emergency management, as well as road maintenance, in the relevant NYSDOT regions (NRC 2010, p. 184).

In the Binghamton area (NYSDOT Region 9), there is some anecdotal evidence for the increased frequency of intense rain storms, with concomitant increased rapid runoff. In one recent event, route I-88 was closed because of flooding. This situation will require both more emergency resources and more focused design and maintenance efforts by the relevant regions.

In the coastal and tidal regions of New York City, Long Island, Westchester and the Hudson Valley (NYSDOT Regions 8, 10, 11, 1), increased coastal flooding from sea level rise and storm surge will require both more emergency resources and design of climate adaptations for long-term structural change.

The overall implication of such differences is that different regions will need to have somewhat different plans and resources, tied together however by an overarching approach to climate change adaptation. A modeling implication is that the NYSDOT and other transportation agencies would want to utilize regional climate models (RCMs) as these become more reliable in identifying smaller scale climate change impacts.

Chapter 4: Adaptation Strategies and Best Practices

4.1 Introduction In this chapter, adaptation strategies and best practices for climate change risk management available to the NYS transportation system are suggested, especially as they relate to the NYSDOT's mission. This information has been developed from an extensive literature review. An overview and key findings of the literature review carried out for this study are given in sections 4.2 and 4.3 in this chapter. The chapter also includes descriptions of the most significant structural adaptation options for NYSDOT for different climate impacts (Section 4.4). These adaptation options were developed from the literature review and discussions with NYSDOT personnel and other experts.

4.2 Literature review procedures and overview A wide range of reports, articles and books was reviewed for the project. The items reviewed were recommended by experts and also were taken from a variety of websites dealing with transportation and climate change in the US and other countries. The material reviewed includes the extensive recent publications on climate change relating to New York City and the New York Metro region (MTA 2008; NPCC 2010) and some reports that discuss adaptation more generally, with reference to the transportation sector. The review was supplemented by discussions with NYSDOT personnel and other experts. While there is no way to insure that the best materials were reviewed in detail, it is believed that the selection employed accurately reflects the state of climate change adaptation in transportation agencies. Materials were examined at several levels of detail, including initial review, preliminary assessment, and comprehensive assessment, as explained in the research protocol in Appendix A. For ease in analysis, the materials assessed in detail were categorized in terms of the topics covered: need for adaptation strategies; vulnerabilities; strategies; institutional arrangements; actual adaptations. It should be noted that, while this chapter is a principal location for the results of the literature review, references throughout the report also stem in part from that review. This applies especially to the climate information in Chapter 2 and the impacts and vulnerabilities information in Chapter 3.

There is a significant amount of research and literature on the vulnerabilities and hazards associated with climate change and the transportation sector (e.g. California Department of Transportation, 2009). Most recommendations are based on a general discussion of the need for adaptation; some reports discuss specific strategies for transportation adaptation. Within that smaller group, some highlight actual adaptation efforts, including institutional arrangements and planning. Relatively few reports deal with the actual design and implementation of climate change adaptations (Lindquist 2007, p. 4). Many reports discuss the need for more research, including recommended possible future areas of study within the transportation infrastructure field. In that regard, National Research Council (2010, p. 83) suggests that the general research approach to adapting to climate change is well established (for example developing paving materials that are more heat resistant), but that effective adaptation will require continued research and application.

A literature review of transportation and climate change (including mitigation) is included in Savonis et al. (2008). This review notes that a large body of work has been

done relating transportation to emissions and climate change, but that less work has been done on the impacts of climate change on transportation. There is relatively little in the review on adaptation. One of the authors' conclusions is that the development of planning strategies is an important need, and that most of the work to date on impacts and adaptation has been from a facilities engineering point of view (Savonis et al., 2008, p. 1-22). Other literature reviews have been conducted, such as in the Adaptation Assessment Guidebook (Major and O'Grady, NPCC 2010, Annex C) and Preparing for Climate Change: A Guidebook for Local, Regional and State Governments (Snover 2007, Appendix D).

In overview, an awareness of climate change, its impacts, the extensive vulnerabilities of transportation systems to climate change, and the need for adaptation has become widespread among transportation agencies and is reflected in the literature (TRB 2008, California Department of Transportation, 2009). It is understandable that transportation agencies, which deal routinely with the often severe impacts of climate variability, should be among the leaders in developing approaches to adaptation to climate change. This holds not only for systems in coastal areas of states such as New York, where significant elements of the transportation infrastructure are at or below the current sea level, but also for inland areas in upstate New York where transportation systems are affected by extreme precipitation events, such as intense rainfall, road and rail icing, and heavy snowfall. Perhaps the best statement of what is currently needed is found in the important report of the Transportation Research Board (NRC, 2008):

> State and local governments and private infrastructure providers should incorporate climate change into their long-term capital improvement plans, facility designs, maintenance practices, operations, and emergency response plans. (NRC 2008, p. 193)

This sentiment is widely shared in the literature reviewed. At the same time, the current situation, as reflected in the literature, is one in which many agencies are at best "gearing up' to take action on climate change adaptation, often in the context of severe budgetary limitations for current operations (e.g. California Natural Resources Agency, n.d p. 23). Gearing up for adaptation to climate change entails at least the development of suitable organizational frameworks; detailed agency operating mechanisms; and the need to begin work on changing design standards to adapt to a changing climate (NRC 2010, p. 202). In the terms of this project's title, this means mainstreaming climate change adaptation into all of the activities of transportation agencies.

The detailed information from the literature review and experts that is especially relevant to NYSDOT is presented here in three parts: organizational, planning and decision frameworks; examples of design and operational adaptation that have been implemented; and finally the principal adaptations to climate change relevant to NYSDOT as garnered from the literature review, the interviews, the researchers' work with other New York City and New York State climate projects, and discussions with experts. This is followed by a brief summary of the main ways in which the literature review contributes to the recommendations of the study, as summarized in Table 5.1.

4.3 Organizational and decision frameworks for climate change in transportation
As overall principles for adaptation to climate change, NRC (2010, p. 20) emphasizes that adaptation should be looked at from the perspective of long-term sustainability, and emphasizes also cross-sectoral approaches and an inclusive approach, linking adaptation to mitigation and sustainability. King County (2007, p. 99) suggests the need for regional approaches to adaptation planning and Savonis et al. (2008, p. 1-22) emphasize the need for developing strategies for climate change.

Perhaps the most comprehensive current discussion of an overall planning framework for adaptation to climate change relating to New York is in the report of the New York City Panel on Climate Change (NPCC, 2010), especially in the adaptation assessment guidelines (Major and O'Grady, NPCC 2010, App. B) and in Yohe and Leichenko (2010), who discuss a risk-based management approach.

The Adaptation Assessment Guidebook (Major and O'Grady, 2010) provides an 8-step framework for risk-based decision making including:

1. Identify current and future climate hazards
2. Conduct inventory of infrastructure and assets
3. Characterize risk of climate change on infrastructure
4. Develop initial adaptation strategies
5. Identify opportunities for coordination
6. Link strategies to capital and rehabilitation cycles
7. Prepare and implement adaptations plans
8. Monitor and reassess

These steps provide a useful way for transportation agencies to structure a risk-based management approach to climate change. As an example, they are used to assess the climate change challenges on the largest public transportation agency in New York State, the MTA, in Jacob et al., 2008, and they have framed much of the work of the New York City Climate Change Adaptation Task Force, a group that was supported by the scientific work reported in NPCC (2010). Other similar frameworks exist, for example in Lim et al. (2005) and the Ireland National Roads Authority Strategic Research Opportunity (2008, ongoing) in the international sphere. Some details of procedure have been developed; for example, King County (2007, p. 110), reports that interdepartmental climate change adaptation team will review a variety of plans and evaluate climate change "readiness" in the County. The Rail Safety and Standards Board in the United Kingdom also supports incorporating the railway industry into the UK Climate Impacts Programme (Eddowes 2003). It can be noted here that processes for planning infrastructure are broadly the same across many sectors (Goodman and Hastak, 2006). By extension, decision frameworks and other information on planning climate change adaptations from one sector can be helpful in considering elements of adaptation in other sectors.

Yohe and Leichenko link the increasing attention to risk-based management approaches for climate change to the inability of traditional benefit-cost analysis to cope unaided with the challenges of climate change:

> A risk management approach to confronting climate change has emerged as a complementary analytic tool that is designed to ameliorate or at least account for many of the limitations of traditional cost-benefit analysis (Yohe and Leichenko, 2010, pp. 30-31).

Benefit-cost analysis will, of course, continue to be helpful in some contexts, especially in comparing alternative adaptations to specific climate hazards. "Risk management approaches to decisions begin with a statistical definition: *Risk = the probability of an event multiplied by some measure of its consequence"* (Yohe and Leichenko, 2010, p. 31). This approach uses such approaches as flexible adaptation pathways to enable agencies to maximize the effectiveness of adaptations over time. The NRC (2008) report also advocates a risk-management approach to transportation decision-making (p. 135-141); NRC (2010, p. 116) recommends a portfolio of options as a means of dealing with risk. Gallivan et al. (2009, p. 17) note the lack of risk management in port planning procedures.

4.4 Examples of adaptation steps, design standards and adaptations that have been implemented The literature review found a number of instances of adaptation steps, design standards, designs and actual construction relating to climate change adaptation. These are not consistent geographically and by mode; rather the current situation is one in which an eclectic mix of particular projects were, perhaps because of both decision-maker interest and professional suggestion, linked to climate change adaptation. Some of these relate specifically to climate change, and some not specifically to climate change, but rather to existing variability; the latter also illustrate types of adaptation that would be required to deal with climate impacts. Together they provide an impression of what has been done; and some of the figures in these cases, using Costanza et al.'s (2006) "Value Transfer Method," may be directly relevant to the NYSDOT.

One of the few examples to take planning further by incorporating climate considerations into a design manual is given in UK Highways Agency et al. (2006), regarding design for increased rainfall intensity. In this document (Sec. 6.3) it is stated that "The rainfall intensities used to calculate the design storms must include an allowance for the effects of climate change. Where rainfall data exclude such an allowance, a sensitivity test on the design of the drainage system must be carried out by increasing rainfall intensities of the design storm by 20%.*"* While this is a rough rule, it is indicative of the types of changes likely to be required in design standards. Hogan et al. (2009, p.41), writing of Placentia, Newfoundland, suggest the use of new standards for culvert design to account for climate change, although these are not set as rules.

An example of actual design for climate change 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 planned portion of the circumferential road north of the Yela Valley. There is a detailed climate-proofed design plan for the road

design, including construction, maintenance and repair costs for the built and planned sections of the road, and estimates of cost differences between initial climate-proof construction and retrofitted adaptation efforts, concluding that it is more costly to climate proof retroactively.

Finally, an example of a large constructed facility that incorporates one important element of climate change, sea level rise, is the Confederation Bridge linking Prince Edward Island and New Brunswick, 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.)

An example of an adaptation strategy that took place for current variability, but that is of a type that will be increasingly required for climate change, is a Federal Emergency Management Agency (FEMA) grant to the town of Freeport, NY. This grant in part went to grading and raising streets in order to prevent flooding. For a total cost of $2.76 million, benefits, on a best-estimated basis, were $6.52 million (Multihazard Mitigation Council, 2005, p. 107). An example of larger costs for adaptation of transportation systems comes from Louisiana, for 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 La Fourche 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 and storm surge. (Savonis et al., 2008, p. 4-55).

As these examples indicate, transportation agencies have not yet achieved across-the-board incorporation of climate change adaptation in their procedures; yet the available examples point the way and show that new design standards are feasible (Lemmen, 2008, Chapter 5).

Although proactive and new design specifications are preferred, adaptive management plays a significant role, thus, the NYSDOT has programs in place that, while not designed for climate change adaptation, can be easily adapted for that purpose. For example, the NYSDOT has a 24/7 emergency command center in Albany to deal with road blockages and outages from extreme events. NYSDOT also has the Hudson Valley Traffic Management Center in Westchester County (Region 8), and participates in the INFORM Traffic Management Center in Long Island (Region 10) and the Joint Traffic Management Center in New York City (Region 11).The NYSDOT is able to move resources among its divisions fairly quickly because of well established emergency response operations that are coordinated through these information centers. If extreme events increase due to climate change, it is possible that the budget for this operation and the associated costs of resource allocation would increase gradually over time; these

budget increases can be considered costs of adaptation. Other ongoing management programs that deal with current variability but could be expanded over time for climate change include emergency control of signals on state highways. Similarly, the Transportation Ministry of Quebec (MTQ) uses a winter maintenance decision support system to adapt to the deterioration of driving conditions in the winter. The MTQ continues to develop and implement fixed and mobile instrumentation across the province (Lemmen, 2008, Chapter 5).

4.5 Structural Adaptations to Climate Change for the NYSDOT There are many available options for adaptation to climate change (NRC, 2008). These include policy, management and infrastructure adaptations. In this section some of the most important infrastructure adaptation recommendations for the NYSDOT are given by climate change impact category (Jacob et al., 2011; NRC 2008, 2010). Many other policy and management adaptations are referred to elsewhere in this report, in Table 5.1, summary of recommendations, and in the reports on climate risk information discussions by division and office. While an integrated overall program for climate change adaptation is needed for the NYSDOT, the actual adaptations used will differ both by Region and by Division.

4.5.1 Sea Level Rise and Storm Surge

- Constructing local flood proofing by building local levees, sea walls, floodgates and pumping facilities (King County, 2007). For very low-lying areas such measures may be effective only for several decades. Site-specific studies for different time horizons will be needed.

- Raising roadways and associated infrastructure in coastal areas. This will be a significant impact for some roads. The elevating of the Louisiana Highway 1 (Savonis et al. 2008, p. 55) and the Confederation Bridge (Lee 2000, Appendix D) are examples of this type of adaptation.

- Designing road embankments as super-levees that could provide a double function: flood protection and transportation corridors.

- Redesign of bridge protection to account for changes in scouring patterns. Bridge pylon impact-protection buffer systems at navigable rivers and waterways subject to sea level rise and storm surge can be vertically extended to provide protection under future higher sea level conditions.

- Designing culverts and ditches for increased storm intensity.

- Relocating road systems and related critical systems to higher locations (NRC, 2010).

- Raising bridge landings and approaches along shorelines to ensure that there is sufficient clearance for the transportation systems (highways, roads, rail systems) they cross over, given the need to potentially raise these systems as a result of sea

level rise and related storm surge inundation hazards (Titus 2009, p. 114). An example is the landings of the proposed new Tappan Zee Bridge, which need to have sufficiently high clearances to accommodate potentially raised road and rail systems along the riverfront.

4.5.2 Adaptations for More Intense Precipitation

- Increasing the carrying capacities of culverts, retention basins and other drainage systems in accordance with future precipitation scenarios. Changes may be needed in drainage guidelines and other applicable engineering standards.

- Insuring adequate maintenance of culverts and other facilities to insure that both current and future designs operate at design capacity and are robust to withstand environmental conditions.

- Raising road embankments and/or strengthening their slopes to be resilient to flow dynamics and bank erosion in river flood zones prone to high flow velocities.

- Relocating roadways out of future flood zones.

- Monitoring and remediating scour action at bridge foundations in rivers at tidal locations as flood and related flow conditions become more severe and frequent.

- Working with other agencies to reduce runoff from nearby properties and other right-of-ways onto transportation systems. There is a variety of ways to accomplish this, including additional permeable surfaces, retention basins, restoration of marshlands, and increase of sewer and pumping capacities and regrading of slopes to direct runoff away from transportation infrastructure (e.g. buffer zones, Eddowes 2003, p. 32-33).

4.5.3 Adaptations for Heat Hazards

- Transportation agencies such as the NYSDOT may need to be prepared for more frequent power failures (and related potential communication failures). This applies especially during extended summer heat waves, when peak power demands exceed what electric utilities can supply due to increased need for air conditioning (unless the utilities' adaptation plans cover these needs, or plans are in place to reduce public demand during such).

- Road surfacing materials may need to be adjusted to some extent to new heat conditions. This and the following two considerations do not appear to be highly significant for NYSDOT at least in the next few decades.

- In combination with sea level rise, the potential for some sagging of large suspension bridges during extreme heat (although a much less important factor than sea level rise) will need to be monitored with regard to how it affects clearances.

- The seat lengths of expansion joints of bridges and/or the range of finger joints may need to be increased to some extent because of new temperature ranges, or a more frequent cleaning and maintenance schedule may need to be established.

- Increased temperatures may pose risks to employees on construction and maintenance projects, and may require preventative measures to reduce risk of heat exposure for their safety.

4.5.4 Adaptations for Winter Storms (Snow and Ice)

Overall snowfall and days per year with snow cover, especially in the downstate portions of New York, are expected to decrease gradually as snow will be more frequently replaced by rain (Horton et al., 2011). On the other hand, individual snowstorms and ice storms (with freezing rain) may become more intense, especially in higher elevations, in upstate regions and those in areas prone to the lake effect, which may be amplified by a shorter duration of ice cover on the Great Lakes. On average, across the state, a net reduction in snow hazard is more likely than not, but no clear trend is yet forecast for future freezing rain and icing conditions.

These geographically diverse trends across the state may require

- Potential reallocation of operational resources for winter snow and ice operations.
- More widespread use of intelligent signs, other road weather information systems, and better forecasting to provide information on inclement weather-related traffic conditions.

4.5.5 Adaptations for Winds

Other climate-related risks that require adaptation measures may originate from more frequent extreme winds (characterized as hard to quantify). Adaptations include:

- Adjusted design wind speeds with time on a per-region basis.

- Installation of anemometers measuring wind conditions on bridges of a certain length and height above ground or water. Wind velocity limits may need to be set above which bridge traffic will be allowed only at reduced speeds or, for higher wind speeds, will need to be suspended entirely to avoid excessive accident rates. Such limitations are already in place on some bridges in New York State (Jacob et al., 2011).

4.5.6 Selected non-structural adaptation options

- Climate change indicators and impacts can be added in project approval in the Environmental Determination under SEQRA and CEQR where applicable on a detailed project by project basis. While it is true that SEQRA and CEQR apply to

individual projects, and thus have limited scope as compared to broader strategic plans for climate change, they can be highly useful tools in incorporating climate change, especially for large projects. Moreover, both of these documents can be strengthened with regard to climate change requirements and applicability.

- Development of plans such as "regional master plans" in the context of climate-change related revisions of land use planning (examples: along mid-Hudson river and coastal areas).

4.6 Potential timing and resources for adaption strategies Adaptation strategies are best undertaken when staged over time to meet changing climate conditions and impacts. This has several implications for the NYSDOT. Among the most important is the need to shift methods to non-stationary analyses for water and climate variables (Milly et al., 2008). This is not a trivial change, as it involves modifying one of the bedrock principles of engineering design: the use of historical data. A recognition of this change was discussed consistently in the conversations on climate risk information. In addition, more than ever, designs must be varied according to the expected schedule of implementation and expected useful lifetime of the structure or project. It will no longer be sufficient to design the "best" project and wait for it to be scheduled in a capital plan, because the definition of "best" will depend on the expected date of implementation rather than on, say, a standard benefit-cost analysis that does not take climate change into account. Further, designs for rehabilitation and replacement of facilities will need to include climate adaptation planning, a potentially large source of savings in implementation costs as compared to last-minute add-ons. A project with an expected useful lifetime with 30 years, vs. one with more than 100 years, especially if located in areas affected by sea level rise, will need different design specifications. All of these considerations lead to the concept of "flexible adaptation pathways," (NPCC 2010), the development of adaptation plans stretching into future time periods that retain flexibility for change, insofar as this is possible with large capital projects, as climate conditions change. Attaining such plans requires the inventory of assets, vulnerabilities, and adaptation options.

4.7 Summary of contributions of the literature review to study recommendations The literature review contributed to the study recommendations in a variety of ways, as did inputs from NYSDOT and other experts. There is an extensive literature on climate change impacts and vulnerabilities and potential adaptations in the transportation sector; among the most important documents are California Department of Transportation, 2009, NRC (2008, 2010), Zimmerman and Faris (2010), Jacob et al. (2011) and Horton et al. (2011). There is also an important literature on overall approaches to climate change adaptation in transportation, including risk management approaches and adaptation assessment steps (Yohe and Leichenko, 2010, Major and O'Grady, 2010, NRC 2008, 2010). There are also some examples of design standards for climate change (UK Highways Agency et al., 2008) and actual adaptations for climate change (Titus, 2002) and for current climate impacts that relate directly to potential future adaptations (Multihazard Mitigation Council, 2005; Savonis et al., 2008), In general, the literature review supports the idea that mainstreaming of climate change into agency adaptations is right for implementation now.

Chapter 5: Mainstreaming Climate Change Adaptation Strategies Into NYSDOT Actions, Including Legislation, Policies, Programs and Projects

5.1 Introduction This chapter presents the summary table of study recommendations (Table 5.1, below). These recommendations are based on: a literature review; discussions with key NYSDOT personnel based on the Climate Risk Information Summary (Appendix 1); information from Columbia's many ongoing and completed projects in climate change adaptation, especially those in the New York region; advice and guidance from the NYSDOT's Technical Working Group (TWG) for the project and other key NYSDOT personnel; and advice and guidance from Columbia's Advisory Working Group (AWG). The divisions or groups that might take the lead in each of the broad categories of recommendations are given in Table 5.1. Section 5.2 is the summary of study recommendations; Section 5.3 includes the detailed results of the discussions with division and office leaders based on the Climate Risk Information Summary. Finally, there is discussion of strategies in terms of organization and training guidelines (Section 5.4); guidelines for planning documents (Section 5.5); linkages to capital planning and rehabilitation cycles (Section 5.6); and keeping current with climate science and adaptation planning (Section 5.7).

The literature review, the climate risk information discussions, the researchers' experience with adaptation in the New York region, and the advice of the advisory groups provided several firm conclusions that suggest the potential shape of organizational efforts to mainstream climate change adaptation into policies and programs. Throughout the climate risk information discussions, for example, there was an interest in and knowledge of climate change as an important issue for the NYSDOT and transportation agencies generally. There was a concern with current climate vulnerabilities such as intense storms, inland and coastal flooding, extreme heat waves, and winds, and an interest in how these would change over time. There was as well a commitment to the NYSDOT's existing programs dealing with extreme events and the potential need to expand these for climate change. From all of these sources of information, the numerous recommendations of this study were developed. These are summarized in Table 5.1. In the remainder of the chapter, important elements of mainstreaming climate change into NYSDOT's operations are discussed in more detail; these discussions complement the narratives of chapters 2-4 and 6.

Numerous intra-agency and interagency coordination initiatives that have the potential to relate to climate change adaptation were discussed during the interviews. Many of these are applicable across laws, financing, administrative responsibilities, public and private transportation organizations, and professional traditions such as those of the American Association of State Highway and Transportation Officials (AASHTO), the Federal Railroad Administration (FRA), Federal Highway Administration (FHWA), Federal Aviation Administration (FAA) and state and local agencies. Some mechanisms for coordination are in place for other purposes that need to be identified and could be expanded to target climate change adaptation. For example, storm water retention for drainage is done for current needs, and could be expanded to deal with more intense

precipitation events. Inconsistencies and conflicts among programs that may develop as the climate changes should also be identified.

5.2 Summary of Study Recommendations (Note: the Divisions or other units that can take the lead in implementing the broad categories of recommendations are given in parentheses; these are summarized in a following table.)

A. Planning Policies and Guidelines (Climate Change and Energy Efficiency (CC & EE) Initiative Engineering, Legal Affairs, Operations, Policy and Planning. Sustainability and Climate Change Section,)

1. The development of planning strategies for immediate decisions, for the medium term, and for the long term is an important need.

2. Planning strategies can best be developed within a consistent set of adaptation assessment guidelines, which can be based on national and other guidance as well as through internal deliberations.

3. A risk-based management approach, where risk is defined as the probability of an event multiplied by a measure of its consequence, can be an important element of climate change adaptation in NYSDOT.

4. Specific adaptation strategies may be best undertaken when staged over time to meet changing climate conditions and impacts.

5. Within adaptation strategies, the use of flexible adaptation pathways enables agencies to maximize the effectiveness of adaptations over time.

6. Climate change adaptation can be most cost-effective when incorporated into infrastructure during replacement and rehabilitation cycles. Integrating climate change adaptation into capital plans in this way is an important element of adaptation. Further, NYSDOT can encourage addition of climate change considerations and requirements to SEQRA and CEQR

7. Regional transportation master plans should address the climate change-related revisions of land use.

B. Organization and Management (Climate Change and Energy Efficiency (CC & EE) Initiative, Commissioner's Office, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. There will be a continuing need for an ongoing internal structure at the NYSDOT to deal with mainstreaming climate change adaptation over the next few years. The newly formed Sustainability and Climate Change Section is to lead this effort, which can include the expanding the current CC & EE Team structure to include a

senior person from each key division and the regions to constitute an Adaptation Team. (Work groups can meet as needed and forward recommendations for review.) Among this teams' tasks could be:

a. Detailed planning for best-practice identification and incorporation into each element of the NYSDOT.

b. Leadership in leveraging the need for climate change adaptation into budget requests.

c. Oversight of training and communications needs.

d. Identifying and progressing research needs.

2. Management programs, such as emergency response strategies, that deal with current variability can in many cases be expanded over time to deal with climate change. In particular, as extreme events increase due to climate change, there can be a proactive increase in budgets to deal with these.

3. Maintenance of the NYSDOT's systems should be undertaken at a high and continuous level to insure that both current and future facilities are resilient to climate change. This refers both to ongoing maintenance and improvements to bring the systems to a state of good repair.

C. Inter- and intra-agency coordination (Administration, Commissioner's Office, Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Legal Affairs, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Mechanisms for coordination for existing purposes can be identified and expanded to target climate change adaptation.

2. NYSDOT can encourage best-practice identification and incorporation in the groups outside the NYSDOT in which the agency participates such as the Metropolitan Planning Organizations (MPOs).

3. Inconsistencies and conflicts among both internal and interagency programs that may develop as the climate changes can be identified; for example, planned expansions and rebuilding of infrastructure in current coastal and riverine flood plains can be reexamined in the light of climate forecasts.

4. NYSDOT can encourage other agencies to reduce runoff from nearby properties and other right-of-ways onto transportation systems.

5. NYSDOT can participate in writing nationally applicable transportation guidelines or standards to ensure that they contain adequate language and

technical content for addressing climate change adaptation (and/or mitigation—NYSCAC, 2010, ch. 7) needs. Some variation in guidelines and standards by state may be appropriate.

D. Regional aspects of adaptation planning (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Climate scenarios suggest different impacts in different areas of NYS, so that adaptation plans and programs will have to vary to some extent by the regions of the NYSDOT.

2. The most important example of differential effects is the impact of rising sea levels and associated higher storm surges on transportation systems in coastal areas and the Hudson Valley (NYSDOT regions 8, 10 and 11 and a part of 1).

3. Although different regions will need to have somewhat different plans and resources across NYS, these plans and resources should be tied together by the overarching approaches to climate change adaptation suggested in this report.

4. NYSDOT will want to track the effectiveness of and ultimately utilize regional climate models (RCMs) as these become more reliable in identifying smaller scale climate change impacts.

E. Vulnerability inventories (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. A full inventory of NYSDOT-owned transportation infrastructure at risk to climate change hazards identified for NYS is essential.

2. Developing a digital data base of all NYSDOT "as built" structural and road bed elevations in coastal areas, at least to elevations up to 20 ft above current sea level is necessary to make reasonable decisions based on projected climate risks including SLR and storm surge.

F. Design Issues (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Sustainability and Climate Change Section)

1. Adaptation needs will evolve over time as climate science, impacts, technological advancements and adaptation strategies are further developed.

2. As available, State-endorsed climate change scenarios should be used, with updates of climate change scenarios taken into account if possible as they become available.

3. Design criteria should take into account the statistically non-stationary probabilities for hydrologic processes and other climate variables.

4. For some facility designs, such as road surfaces and expansion joints, new heat thresholds may need to be considered.

5. Program and project designs should be varied according to the expected schedule of implementation and according to the expected useful lifetime of the structure or project, because the appropriate design should be for the climate variables and impacts expected at the date of implementation and beyond.

6. Designs for rehabilitation and replacement should include climate adaptation planning, rather than being simply replacements of existing designs.

G. Infrastructure Adaptations (Engineering, Operations, Sustainability and Climate Change Section)

A range of infrastructure adaptations has been identified for NYSDOT purposes. Some of the principal ones are given here. (Institutional, policy and management adaptations are given above; see also NYSCAC, 2010, ch. 11.)

1. Sea Level Rise and Storm Surge

    a. Implement local flood proofing (sea walls) for State highways and other roads in the National Highway System

    b. Design road embankments, including bridge landings and approaches, as levees when possible and appropriate

    c. Elevate or relocate road systems and other critical systems to higher ground

    d. Design culverts and ditches for increased flooding

    e. Raise bridge landings and approaches

    f. Redesign to account for changes in scouring patterns

2. More intense precipitation

    a. Increase the carrying capacity of culverts, detention basins and other drainage systems to deal with potentially increased storm intensity

    b. Ensure adequate maintenance to achieve full design capacity

c. Raise road embankments and strengthening slopes

d. Raise or relocate roadways out of flood zones

e. Monitor scour action at inland bridges and remediate as required

3. Heat hazards

a. Reduce possible impacts on buildings and building materials.

b. Reduce impacts on road materials and bridge expansion (likely to be less significant.)

4. Winter storms

a. Flexibility in potential reallocation of emergency resources

5. Winds

a. Reconsider design wind speeds

b. Monitor wind conditions at selected sites; obtain data from NOAA

H. Monitoring and assessment (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. Monitoring and reassessment are critical components of any climate change adaptation plan; they relate both to the plan itself and to observed changes in climate and climate impacts. A wide range of elements for monitoring is presented in this report

2. Monitoring adaptation plans in the region should be done both to determine if they are meeting their intended objectives, for example to provide adequate drainage, and to discern any unforeseen consequences of the adaptation strategies

3. Monitoring of weather and climate including detailed site-specific climate impacts can often be done most effectively by personnel already on the ground

4. Monitoring of climate and detailed site-specific climate impacts can also be done effectively by automated and remote technologies, which should be regularly reassessed for applicability.

I. Training needs (Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section, Workforce Learning and Development Bureau (Administration Division))

1. Training for staff for climate change adaptation will be a central part of NYSDOT's response. Such training can include the topics of:

   a. Climate science

   b. Future climate scenarios

   c. Changing guidelines for NYSDOT design, construction and operations,

   d. The overall framework of planning for climate change, including adaptation assessment steps.

   e. Monitoring methods for site-specific climate impacts

2. Training can be in-person or through webinars and other electronic methods.

J. Communications (Administration, Climate Change and Energy Efficiency (CC & EE) Initiative, Engineering, Operations, Policy and Planning, Sustainability and Climate Change Section)

1. There is a need for continued and enhanced engagement with professional organizations, local universities, and other state-wide adaptation initiatives, such as the Climate Action Council and the New York State Sea Level Rise Task Force

2. An appropriate role for NYSDOT includes providing relevant climate adaptation guidelines and design criteria to local groups.

K. Research needs (Administration, Engineering, Policy and Planning, Sustainability and Climate Change Section)

1. A particular need is for research into how general climate change projections can be expressed in terms that engineers can use in designing transportation facilities. An example is the need for new design criteria for planning drainage systems in conditions of more intense precipitation.

2. Research is required into the best scope and methods for monitoring climate change impacts in NYS.

3. Mapping of areas at risk from sea level rise, storm surge, and inland flooding is a major need in order to identify transportation system vulnerabilities.

4. NYSDOT can make arrangements to ensure that updated climate information and scenarios are available on a regular basis.

A summary of the Divisions and other units that can take the lead in various categories of recommendations is provided in the following table.

Table 5.1: Lead Roles by Categories of Recommendation

Category of Recommendations	Division or other unit							
	Comm. Office	Admin.	CC &EE	Eng.	Legal Affairs	Opera-tions	Policy & Plan.	Sustainability & CC Section
A. Planning policies and guidelines			X	X	X	X	X	X
B. Organization and management	X		X	X		X	X	X
C.Inter- and Intra-agency coordination	X	X	X	X	X	X	X	X
D. Regional aspects of adaptation planning			X	X		X	X	X
E. Vulnerability inventories			X	X		X	X	X
F. Design Issues			X	X				X
G. Infrastructure				X		X		X
H. Monitoring and Assessment of Adaptations			X	X		X	X	X
I. Training needs		X	X	X		X	X	X
J. Communications		X	X	X		X	X	X
K. Research needs		X		X			X	X

5.3 Interviews with Division/Office/Regional Managers This section provides summaries of the interviews conducted as part of the research project with Division/Office/Regional managers in NYSDOT. The Climate Risk Information Summary (CRIS) (Appendix 1) was used in each interview as a basis for discussion. The CRIS is organized in several sections, including Relevant Systems and System Aspects; Climate Impacts and Adaptation; System Ownership and Control; Capital Planning; and Additional Information and Suggestions. The document was designed to help assess overall awareness of climate change, adaptation planning and related issues, and thus to serve as one of the bases of the recommendations of this report.

The Divisions and Offices with which climate information discussions were held are among those in the NYSDOT with programs highly relevant to climate change adaptation; however, to some extent climate change will impact almost all of the NYSDOT's programs. In this regard, more general adaptation issues relating to climate change and NYSDOT as a whole are applicable as well as those that are specific to Divisions and Offices. The Divisions and Offices for which mainstreaming findings and suggestions were developed are listed first by Divisions (Operations, the largest, and Engineering); these are followed by Offices grouped by Division: 3 from Operations; 6 from Engineering; 1 from Legal Affairs, and 2 from Policy and Planning. The last section is a discussion with personnel of NYSDOT's Region 1.

The material from the discussions was reviewed by the interviewers and has been placed in bullet form for this report. At the end of the information for each Division, Office, or Region, the date of the interview is given. Most of the comments in the discussions relate to the specific Division, Office, or Region of the personnel involved, but some comments also relate more broadly to the NYSDOT. Many of the detailed comments on issues directly relating to the interviewees' work have formed the basis of recommendations on inventories, adaptations, and design as well as other topics.

Some topics pertaining to mainstreaming climate change adaptation that were discussed deal with current climate variability, and are therefore well positioned to transition to considerations of climate change when appropriate. There are other programs relating to public information, staff training, and inter-agency coordination that provide immediate opportunities for mainstreaming. In these cases, the researchers attached an asterisk to the topic; the sum of these for each Division or Office could serve as one component of an initial program of climate change adaptation. In other cases, such as the many changes in rules and procedures that are likely to be needed over time, a start can be made by "planning for planning" in the near term, even if completing the work is a long-term proposition both because of the complexity in changing laws, rules and procedures and in some cases the need for more monitoring. Finally, some elements involve long-term infrastructure decisions that may not be made immediately; these can be at a minimum identified and scheduled for planning at a later date. All of the elements, however, deserve incorporation in an overall "plan for planning" for climate change adaptation in the NYSDOT. All of these conclusions from the climate risk information discussions have greatly informed the recommendations of this report.

The Divisions and Offices in the NYSDOT generally perform two types of activities: administrative activities, including the development of policies and procedures; and production activities, which include planning, design, construction and maintenance for transportation facilities. Administrative activities tend to be more concentrated in the Main Office, while production activities are performed in the Regional Offices. However, both types of activities occur in both locations. The magnitude of the activities that the NYSDOT performs around the state varies by the number of facilities for which the NYSDOT has responsibility, the demand on those facilities, and weather-related and other maintenance activities for those facilities. Opportunities for mainstreaming climate change into the NYSDOT's activities will therefore also have regional dimensions. All Divisions and Offices also participate in the 5-year capital planning of the NYSDOT, as well as in longer-term planning activities. All of the interviewees were fully engaged in the rolling 5 year capital plans, and also were cognizant of the 12 year plans that are developed from time to time and the 20 year State plans required by the Federal government. Integrating climate change adaptation into these plans can be an important part of budget proposals, demonstrating the commitment of an agency not only to effective but also efficient adaptation.

Representatives of the various components of the NYSDOT serve on the Department's Climate Change and Energy Efficiency Team, as well as on the NYS Climate Action Council and other climate-related groups. Thus, there is already inter-group activity and transmission of information within NYSDOT and with other agencies.

All of the interviewees were conversant with climate change, and several had gone into the details of what is known scientifically in some depth. In particular, the interviewees were aware of the significant changes in engineering design and operations standards that could be needed for successful adaptation to climate change in NYSDOT. Especially there was an awareness that the use of historical data was no longer appropriate as the sole criterion for decisions at a time when non-stationarity in hydrologic and other processes is expected to be the norm rather than the exception.

These conclusions bolster a conclusion from the literature review, which is that on balance NYSDOT is at the forefront of efforts to discern the best ways to mainstream climate change adaptation into its operations and programs. The recommendations in this report are designed to help NYSDOT move ahead from its current favorable (although budget-restricted) position.

5.3.1 Interview summaries.

The **Operations Division** is the largest Division in NYSDOT in terms of employment. It includes the Offices of Transportation Maintenance, Traffic Safety and Mobility, Modal Safety and Security, Fleet Administration and Support, and Employee Safety and Health. Opportunities for mainstreaming climate change adaptation into the work of the first three of these Offices are given below. The opportunities given here are for the Division more generally, and include many of those given for the individual offices.

- Because of the strong organizational structure of Operations and the comprehensiveness of the Division's work, which includes some construction through maintenance activities, there are many opportunities for mainstreaming climate change adaptation.
- The Division has the capacity to respond to climate change through adaptive resource management.
- Mainstreaming will not simply involve hardening everything, but rather also looking at entire systems for adaptation—looking ahead to transportation sustainability. An example of systems thinking is culvert design—bigger culverts may be needed, but they may flood downstream areas more quickly.
- The Division, with its substantial employment, is well placed to cooperate in coordination among groups interested in climate change.
- There are opportunities for communication of climate change concerns to municipalities and other stakeholders, to help them plan and coordinate.
- For many climate change impacts on operations, such as ice and snow storms and changing storm intensity, there will be a need for regular updates on climate data and on advances in climate science.
- Most replacement of structures is now in real time, without considering climate change, but climate change scenarios go far into the future. There are therefore many opportunities for planning ahead for replacements that include climate change. Among other things, the time periods between replacements might change.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Operations Division, interviewed on January 22, 2010.

The **Engineering Division** is the second largest in NYSDOT in terms of employees, with about 3200. Its mission is to develop and deliver transportation projects, provide related specialty expertise, develop and issue technical policies, standards and guidance, and provide technical training for the Division and its stakeholders. The Division has 8 Offices, including Construction, Design, Real Estate, Environment, Major Projects, Regional Affairs, Structures and Technical Services. Opportunities are given for the Division as a whole, but include many of those given below for the individual offices. Opportunities for mainstreaming climate change adaptation into the work of each of the Division's units except Real Estate are relevant; for the latter Office, climate change may come into play in the future if coastal roads need to be relocated. (See page 61 for the use of the asterisk.)

- *Climate change can be added to road and bridge design, design review and inspection criteria.
- Storm intensity and frequency standards for design and maintenance can be updated to reflect expected climate change impacts, including expanding the criteria and data used in the standards.
- It may be helpful to increase the frequency of standards reviews.
- *Climate change considerations and requirements can be added at two points in project approval: the Environmental Determination under SEQRA and CEQR where applicable, and the Design Approval point.
- Because localities mainly follow NYSDOT standards for most roads, climate change elements in those standards will have impacts beyond state highways. There are opportunities for outreach in this regard.
- Since the Division already works with MPOs, there is an opportunity for cross-agency and multimodal integration of climate change considerations.
- Flexible approaches to design lifetimes (for example building for shorter lifetimes, or alternatively building for longer lifetimes with greater resilience) can be studied as potential adaptations to the uncertainty of climate change—as a strategy for approaching the unknown
- NYS bridge standards can be more stringent than Federal requirements, an example of how NYSDOT could lead on climate change adaptation.
- The Division has worked with water quality and drainage infrastructure; this subject will be impacted by climate change.
- The Division could move ahead with support of studies on adaptation that have already been suggested.
- Replacement wetlands can be constructed (and monitored) with climate change criteria (for example changing regional precipitation and droughts) as part of the design mix.
- Sea level rise and tides in the Hudson Basin can be monitored to adapt Hudson River bridge design, inspection and maintenance to climate change conditions.
- *There are opportunities to link mitigation, which has been the Department's focus, to adaptation by virtue of its design and design review authority.
- Opportunities exist to combine climate change needs with other functions and responsibilities.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments from NYSDOT, of representative(s) of the Engineering Division, interviewed on January 21, 2010.

The **Office of Modal Safety and Security** is located in the Operations Division of NYSDOT. Its mission is to promote the safe transportation of people and goods in New York State, and to assist passengers and freight transportation providers in establishing proactive safety, consumer and accident prevention programs, and in complying with safety and regulatory requirements. The OMSS oversight authority encompasses bus safety, truck safety, rail safety, motor carrier safety and compliance, commercial vehicle credentialing and permitting and security program monitoring and coordination (http://www.nysdot.gov). This section lists findings and issues relating to adaptation to climate change for this Office.

- As sea level rises and storm surges increase, the Office can contribute to long-term planning for repositioning assets; in the meantime, the Office can assist in monitoring flood events relating to safety and security.
- *With respect to facilities maintenance, inspectors should have training in examining, reporting on, and providing suggestions to deal with climate change-related safety issues such as those related to flooding, winds and ice storms.
- As climate changes and storms, winds and ice storms may increase, there may a need for expanding the emergency response program.
- With climate change, there is likely to be a need for increased communications capacity in emergencies, including back-up for storm events.
- *Regarding monitoring, monitoring for climate change should be part of high-accident locations. In addition, climate indicators can be added to data already being tracked.
- *A commitment to climate change adaptation can be built into the funding arrangements for rail systems partially funded by NYSDOT,
- With respect to Federal regulations for safety and security, the Office could take the initiative on climate change to go beyond Federal requirements.
- As part of safety and security for any new (high-speed rail) or rehabilitated systems (roads, bridges) the Office can contribute to NYSDOT discussions of climate change needs.
- There may be an opportunity to add a climate change component to the annual commercial vehicle plan.
- Opportunities may exist where security, safety and climate change needs are similar, thus, synergies can be identified.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Modal Safety and Security, Operations Division, interviewed on January 22, 2010.

The **Office of Traffic Safety and Mobility** is part of the Operations Division of NYSDOT. Its mission is to provide a safe and efficient transportation environment for its users through the application of sound traffic engineering principles. The Office is composed of the Traffic Operations Bureau, the System Optimization Bureau, the Safety Program and Technical Operations Bureau, and the Emergency Transportation Operations Bureau. The Office works closely with all Department program areas, other public agencies, local governments and the private sector to accomplish its mission (http://www.nysdot.gov).

- *For this office, with its extensive emergency response programs, it will be important to have all of the cooperating groups and agencies using the same climate projections. While climate will change relatively slowly in terms of emergency response times, personnel should be on the alert for changes, such as climate change-related signal outages. An every-five-year checkpoint for climate integration into operations would be helpful.
- *The Office's monitoring systems could be integrated with broader NYSDOT and other climate monitoring systems.
- Emergency response systems can be adapted to expected climate change, as for example in evacuation plans, systems and signal operation, and deployment of resources.
- Opportunities to link the required mitigation components for CMAQ (Congestion, Mitigation Air Quality) funding to climate change adaptation can be explored
- Signal optimization can take into account climate change (for example through adaptation to changing storm intensities and frequencies), and the latter can be a driver of additional resources for signal optimization that is required in any event
- *Because the Office has staff on the ground, there are opportunities to train staff to observe detailed extreme events and their impacts that may not be part of overall scenarios
- The Office will have opportunities, with additional funding, to consider long-run operations planning to take into account climate change and other changes, such as population growth.
- Opportunities to develop information exchanges with states facing similar climate changes that impact emergency management can be explored.
- Climate change suggests more redundancy in emergency systems, and especially to energy and communications infrastructure.
- *There are opportunities to exchange information with funded transportation systems, such as Amtrak, on emergency procedures related to climate change.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Traffic Safety and Mobility, Operations Division, interviewed on February 12, 2010.

The **Office of Transportation Maintenance**, the largest entity in NYSDOT, is located in the Operations Division. The mission of the Office is to preserve, repair and safely operate the State's highway and bridge infrastructure. In accomplishing this mission, the Office works closely with both Department program areas and a wide variety of stakeholders. For maintenance work, there are units below the Regions, called Residencies, which are generally contiguous with counties, although large counties might have more than one Residency. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- Extreme events such as winds, storms, freezing rain and flooding have great impacts on the work of the Office.
- Climate change may bring about the necessity to reallocate resources among regions and residencies.
- *The Regional Directors of Operations, who allocate resources among residencies, can keep abreast of climate trends to assist in long-term maintenance planning.
- Working and repair schedules may have to account for more extreme weather conditions especially the number of days with extreme heat and or extreme precipitation events.
- Main Office and regional and residency staff in the Office have the potential to evaluate which maintenance strategies work for climate change adaptation and which are not as effective.
- Office staff regularly work with local agencies under certain circumstances, such as State-declared emergencies, and these connections offer long-term channels for integrating adaptation throughout the State system, not just State-owned roads.
- Culvert and other designs can be impacted by population growth, development, water quality considerations, habitat connectivity and climate change; the latter can be integrated into already existing mechanisms for design and maintenance review.
- Standards for Municipal Separate Storm Sewerage System (MS4) identification for storm water runoff should be updated at appropriate times to take into account climate change. With help from the Office of Environment, Maintenance can help to provide information of this type to local agencies, as for example when there are requests for access to the right of way.
- The existing materials management system can be a source of monitoring for climate change, by linking materials use to climate trends if staff and funding are available for this purpose.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Transportation Maintenance, Operations Division, interviewed on February 12, 2010.

The **Office of Construction** is located in the Engineering Division. The office provides a range of services, including information on bidding and letting of contracts, approved materials lists, prevailing wage information, safety and health, and a variety of construction related specifications both standard and special (http://www.nysdot.gov). This section provides findings and issues relating specifically to the Office.

- *One important element of climate change relating to this program's operations depends on the program's authority to correct design standards, relating to such things as materials used. Materials specifications, for example, are critical for heat tolerance and water corrosion, two potential effects of climate change. This authority provides an important way for NYSDOT to begin the process of upgrading standards to meet the challenges of climate change.
- Work standards may need to be adjusted to adapt to climate change, including the effects of heat, longer working seasons, and more intense precipitation.
- To the extent that the Office deals with the details of facilities location, climate change can be taken into account in such decisions. The climate change impacts involved would include sea level rise, storm surge, and more intense precipitation.
- *Because the Office has staff "on the ground" it can obtain information on local conditions that could be incorporated into the overall climate change monitoring program of the NYSDOT. For example, these staff members will be aware of local drainage issues that are important for present and future designs, both from their own observations and contact with local planners.
- There may be Federal programs in the future for mitigation and adaptation that can be used for climate change adaptation in addition to those that are currently in place.
- Maintenance issues may become more important in the future because of climate change, and the Office's activities may require larger budgets to stay ahead of these, especially if maintenance practices change dramatically in response to climate change needs.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Construction, Engineering Division, interviewed on January 22, 2010.

The **Office of Design** is located in the Engineering Division. Through its three constituent bureaus, Design Quality Assurance, Consultant Management, and Design Services, it provides an array of services to NYSDOT, including: developing, issuing, and maintaining guidance for highway design functions; managing design consultant agreements; providing statewide photogrammetry and mapping for capital projects, and designing over $40 million per year of moderate and complex capital projects. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- An important step that might be taken in the Office's work is to incorporate climate changes, such as higher temperature, increased rainfall intensity, and sea level rise, into design standards. For example, the Office uses rainfall intensity information provided by the Natural Resources Conservation Service (NRCS) for designs for culverts and bridges; updates by them and NOAA would be included in new designs. Because of the costs of changing design standards, solid information and consensus are required prior to making changes.
- Culvert designs are already conservative, with 50-year storms used typically, and 100-year storm checks in floodplains and floodways (now required by U.S. Army Corps of Engineers (USACE) Regional Conditions to provide aquatic connectivity).
- *Climate change considerations in design would be included in any new standards and incorporated into consultant contracts.
- *Staff can be provided with opportunities to learn about the details of climate change in order to incorporate the relevant impacts into projects designed within the Office.
- Attention to the degree of paved area in terms of permeability of surfaces and of water quality, already a focus of the Office, may become more important in the future to adapt to both more floods and more droughts.
- Culvert designs can take into account expected climate change over the useful life of the culvert.
- *The availability of emergency contractors on call for extreme events may need to be expanded as climate changes.
- *The Office works with the New York State Department of Environmental Conservation (NYSDEC), and can contribute to climate change discussions with that Department.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Design, Engineering Division, interviewed on February 5, 2010.

The **Office of Environment** is located in the Engineering Division. Its work spans a wide range of environmental matters, including air quality, cultural resources, noise analysis, hazardous waste, groundwater, and others. Among the opportunities that may be relevant to mainstream climate change adaptation into the Office's activities are:

- The Office has the opportunity to examine the impacts of climate change on the transportation system as a whole; this will provide a fine entrance point for overall NYSDOT planning for climate change adaptation.
- There are opportunities for further studies, such as changes in storm frequencies and associated impacts on structures, which would support the Office's mission.
- *Because of its wide range of activities, there will be opportunities and a need for the Office's staff to engage climate scientists on a regular basis.
- Rising temperatures are a climate impact that could be more thoroughly integrated into the Office's work, especially with respect to materials.
- Secondary impacts of climate changes, such as changes in transportation systems (as for example, railroads servicing agriculture) can be studied to aid in future planning.
- *The Office has the opportunity for public information activities related to climate change and the need to adapt.
- *The Office can continue and increase its involvement in the CC & EE Task Force activities in NYSDOT.
- *The Office can provide inputs on climate change impacts and adaptations through NYSDOT's membership in MPOs.
- NYSDOT specifications for road-building and bridges are used by most localities; changing these to account for climate change would therefore be of value to these programs as well as to NYSDOT's work.
- *Environmental considerations are linked to many agencies and stakeholders, and the Office can provide leadership in this respect. This includes making clear to Federal agencies the needs of the State regarding climate change adaptation.
- The Office can contribute to the development of State-wide transportation plans, and to the incorporation of climate change in them. Having climate change in these documents is an important basis for moving ahead.
- *The Office can help to develop climate change guidelines that will assist in choosing alternatives among potential projects.
- The Office can also assist in defining hurricane and nor'easter evacuation routes as these might change with climate change (e.g. sea level rise).

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Environment, Engineering Division, interviewed on January 21, 2010.

The **Office of Regional Affairs** is located in the Engineering Division, and is charged with managing capital operations and programs in NYSDOT's 11 regions. This is a key responsibility, as the regions employ the vast majority of NYSDOT's staff and are where the on-the-ground work of the Department is conducted, incorporating local conditions. The Office has monthly Regional Director meetings and bi-weekly calls to help insure effective communication between the regions and headquarters. Among the opportunities for the Office to mainstream climate change adaptation into its activities are:

- The Office can be a key element in encouraging and including climate information in ground-level information gathering. In particular, climate change indicator sets could be included in the inspection list for roads and bridges.
- Among concerns that could be integrated into decision-making is sea level rise on Long Island, where NYSDOT is responsible for many roads, as well as sea level rise as it impacts counties along the Hudson River.
- In rebuilding, climate change considerations can be incorporated into new designs, rather than simply replacing a road or bridge with infrastructure of the same design.
- Lake freezing and thawing and lake effect snowstorms are matters that will be affected by climate change, and the relationship of climate change to these parameters could be evaluated.
- There is a need for updating flood recurrence intervals and rainfall intensity-duration-frequency (IDF) curves for regional use, as changes in these will have significant implications for design and maintenance.
- NYSDOT has guidelines in addition to Federal regulations, and these will provide an entry point for considering climate change.
- Checkpoints can be built in to insure that climate change is taken into account in long-lived infrastructure. Some large costs can be extended over time by use of financial mechanisms such as bonds.
- *There is a potential for increased climate change monitoring through the Incident Command Structure system.
- *There is a need for public information programs to explain the need for incorporating climate change in the design of long-lived infrastructure, including adapting to sea level rise.
- *The Office has the opportunity to work with multimodal systems both in the New York Metro Area and throughout the State, and therefore to encourage consideration of climate change across modes and other transport operating agencies.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Regional Affairs, Engineering Division, interviewed on February 12, 2010.

The **Office of Structures**, located in the Division of Engineering, is responsible for almost all aspects of bridge evaluation, design, quality assurance and construction support. The office also is typically responsible for large sign structures and larger culverts. In addition to its wide-ranging activities, the Office serves as a kind of in-house consultant to other Offices. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- In its inspection activities, the Office can consider the impacts of climate change on bridges and other structures.
- The Office can assist the Division and Department in incorporating climate change considerations into engineering standards for bridge design. These standards include both AASHTO and State standards,
- *The Office can be in touch with climate scientists for information on future climate conditions, and how they will impact bridges (including sea level rise, storm surge, and extreme events).
- The Office can consider expanding the list of bridges to monitor during extreme weather events to take account of climate change.
- Bridge monitoring programs during floods can be integrated with climate change information.
- The underwater inspection program can be expanded to incorporate additional needs from sea level rise, storm surge, and more intense inland storms, such as the incorporation of bridge scour, which has already been done.
- *The Office can develop outreach programs on climate change for non-State agencies and other stakeholders who own and operate bridges that are inspected by the Office. These include municipally-owned bridges. Toll authorities must by law inspect their own bridges, but the Office could have outreach programs for them also.
- Overall, the Office deals with long-lived infrastructure, and therefore has many opportunities for long-term incorporation of climate change adaptation into bridges, overhead signs, and culverts. There will be opportunities for the development of flexible adaptation pathways, and scheduling of adaptations during rehabilitation.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Structures, Engineering Division, interviewed on February 5, 2010.

The **Office of Technical Services** is located in the Division of Engineering. It has four bureaus: Highway Data Services, Geotechnical Engineering, Materials, and Transportation Research and Development, as well as a Pavement Management Unit. Through its constituent units, the Office collects and processes highway data, manages earth, rock and groundwater studies, assesses the performance of materials, guides research, and manages pavement selection and performance. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- Climate change will affect the choice of pavement materials, especially with respect to changing temperatures but also regarding permeability as a factor to control run-off; the Office already has experience in dealing with different materials for different conditions statewide, which will facilitate adaptation to climate change in this respect.
- Changing storm frequencies and intensities will impact the work of the Office, through changing designs and materials for pavements and culverts, and for longer-span bridges where there are sea level impacts.
- As climate changes, there will be increased necessity for data-sharing among this and other NYSDOT offices and stakeholders.
- More intense storms may create more problems with rock falls and erosion of embankment slopes, and thus impact design and materials choice.
- Traffic and weather data can be supplemented by climate scenarios to examine future issues of impacts and materials.
- The quality assurance program for materials provides another avenue for including climate change in the Office's programs.
- *The office works with a variety of Federal, State and local agencies, and can help to incorporate climate change considerations in joint review and decision-making.
- For some local projects, the Department's regulations apply; for cases off the State highway system where these do not apply, the Office could work with localities to insure consideration of climate change.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Technical Services, Engineering Division, interviewed on February 12, 2010.

The **Office of Legal Affairs** of the Division of Legal Affairs has as its primary mission to provide high quality legal advice and services to the Commissioner, Department program staff and the Executive Chamber. It deals with all elements of NYSDOT's mission. Among the main adaptation considerations that relate to the Office are:

- The Office has an opportunity to review a wide range of regulations to help improve their applicability to climate change adaptation.
- The Office can expand the activities it currently undertakes in connection with the federal government, for example, erosion control projects of the US Army Corps of Engineers, where these activities are pertinent to climate change.
- *To the extent that the Office participates in the development of public policy, there will be opportunities to include climate change adaption considerations.
- The Office, by participating in project development and approval, can assist in bringing climate change adaptation into all such decisions.
- The Office's work in wetlands mitigation provides an example of and further opportunities for integrating climate change into wetlands management.
- *For modes to which NYSDOT provides financing, such as Amtrak, the Office can contribute to the incorporation of climate change into the operation of these modes, such as crossing and bridge designs
- *Through NYSDOT's pass-through role for funding local roads, the Office can contribute to climate change considerations. In general, the Office's contractual functions can help expedite funding and resource allocation for climate change programs.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Legal Affairs, Division of Legal Affairs, interviewed on February 4, 2010.

The **Office of Integrated Modal Services** is part of the Policy and Planning Division. It has four bureaus: Public Transportation, Aviation, Freight Rail, High-Speed/Intercity Passenger Rail, and one section, Bicycle/Pedestrian. The Office, which is not an operating office, deals with all modes of transportation except roads and bridges primarily through funding, communication, and regulation. Funds are both Federal and State. Among the main adaptation considerations that relate to the Office are:

- *In all its contracting efforts, the Office may have opportunities to encourage the incorporation of climate change adaptation considerations in management, investment, and policy decisions across all of the modes with which it deals. These include:
    - Air transport: contracting operation of Stewart Airport to the Port Authority and the ownership and operation of Republic Airport. The latter has been determined to be a potential backup facility to the main NYC airports, because it is at a higher elevation than the major airports, a factor relevant to higher storm surge from climate change.
    - Amtrak: all elements of climate change adaptation are relevant to Amtrak, including sea level rise, storm surge, and extreme events. An example of adaptation is the possibility of burying elements of signal systems to avoid wind and rain damage.
    - Ports: these are run by port authorities, and receive funds through NYSDOT; relevant climate change considerations are, depending on port location, sea level rise, storm surge, lake and river levels, and extreme events.
    - LIRR: funded for some programs, relevant climate change elements include sea level rise, storm surge, and extreme events.
    - Ferries, including the Staten Island, Lake Champlain, and other systems.
    - Pedestrian and bicycle routes on state highway systems can be affected by the Office's programs and funding; relevant climate elements include rising sea levels.
- The Office has approval authority relating to the disposition of surplus real property of rail lines after the cessation of service is authorized by the Federal Surface Transportation Board; climate change adaptation is relevant for these both for reuse and safety of abandoned lines.
- In its funding activities, the Office could encourage more inspections relating to climate change, such as the impacts of heat on tracks or post flooding surveys near shorelines and riverbanks.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Integrated Modal Services, Policy and Planning Division, interviewed on March 2, 2010.

The **Office of Regional Planning and Program Coordination** is located within the Policy and Planning Division. It provides a range of planning and coordinating functions within the Division, including public outreach. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- *Although budgets are tight now and at present program updates don't talk about climate change, it will be appropriate for the Office to begin "planning for planning" for adaptation to climate change.
- *With the public outreach activities of the Office, there are many opportunities for assisting stakeholders to incorporate climate change impacts in their planning.
- There are opportunities for engaging with other Offices in monitoring climate change impacts, which may include more frequent ice storms.
- One entry point for considering climate change and public outreach would be potentially more intense storms and floods. Storms several years ago shut down east-west roads, and grocers in PA trucked commodities on north-south roads.
- *The system for immediately establishing cost centers for emergencies is one that will adapt well to climate change.
- *Money is passed through to localities through the Consolidated Highway Improvement Program, and there may be opportunities for increasing concern with climate change in this regard.
- *Multi-modal grant programs also provide opportunities for increasing concern with climate change.
- *The Federal funding for road/railroad safety crossings provides a further opportunity for including climate change, especially more intense storms and sea level rise and storm surge.
- If funding for railway branch lines and industrial access continues, this can be used within the context of planning for climate adaptation.
- The Office can contribute to incorporating climate change considerations into long-term planning for NYS transportation.
- Combined sewers upstate will be affected by more intense storms; so that there is an opportunity for climate change planning here.
- NYS regulates commercial vehicles more strongly than does the Federal government; this is a good example of the potential for going beyond Federal rules in other respects, such as climate change.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of the Office of Regional Planning and Program Coordination, Division of Policy and Planning, interviewed on February 4, 2010.

NYSDOT Region 1 (Capital District) is one of the 11 regions of the Department. Region 1 encompasses 6,580 square miles with a population of about 1 million; it includes Albany, Essex, Greene, Rensselaer, Saratoga, Schenectady, Warren and Washington Counties. The Region maintains 5,300 highway lane-miles and 828 state bridges. The Capital District Transportation Committee and the Adirondack/Glens Falls Transportation Council are the two Metropolitan Planning Organizations within the region. Among the many opportunities for the Office to mainstream climate change adaptation into its activities are:

- *As the direct operating elements of NYSDOT, the regions have the opportunity to make important contributions to monitoring of climate change indicators, such as the apparent shift to less snow and more ice, and the apparent shift to more intense storms, potentially rendering culvert designs inadequate.
- *Similarly, the Regions work directly with local stakeholders, and therefore can work with them in beginning to incorporate climate change considerations in capital planning and maintenance.
- Region 1 includes the upper tidal reach of the Hudson, and therefore will have the opportunity to consider sea level rise impacts on low-lying transportation routes such as I-787.
- The bridge inspection function of the Regions also provides them with the opportunity to begin integrating climate change adaptation into bridge maintenance and replacement.
- *The Regions may need to engage in "planning for planning" regarding climate change, because of intense budget pressure to accomplish immediate needs.
- The Regions have direct contact with the FHWA, and therefore have the opportunity to advance climate change considerations in Federal regulations.
- One adaptation to climate variability, solving the problem of signs wrapping around cables with high winds, suggests the potential for innovation for climate change.
- *Operation of the emergency responses (in which the Regions often do initial work, followed by contractors), provides a further opportunity for ground-level monitoring of indicators.
- One of the most important opportunities for the Regions lies in their role in providing the main office with an inventory of investments and maintenance to be done, and prioritizing among these. This can be a substantial opportunity for mainstreaming climate change in NYSDOT.

The above information presents views and perspectives, as summarized by the research team with additional editorial comments by NYSDOT, of representative(s) of Region 1, interviewed on March 2, 2010.

5.4 Organization and training guidelines. A principal conclusion that the research team draws from the above discussions and other sources is that there will be a continuing need for an ongoing internal structure at the NYSDOT to deal with mainstreaming climate change adaptation over the next few years. The newly formed Sustainability and Climate Change Section is to lead this effort, which can include expanding the current CC & EE Team structure to include a senior person from each key division and the regions to constitute an Adaptation Team. This group could meet regularly as an officially constituted team to map out the needs for climate change adaptation planning in each part of the NYSDOT. This would include: detailed planning for best-practice identification and incorporation into each element of the NYSDOT as well as the groups outside the NYSDOT in which the agency participates, such as the MPOs of which the agency is a member; and to coordinate climate change activities with other transportation agencies in NYS. The team would also take the lead in leveraging the need for climate change adaptation into budget requests. Where possible, personnel at the operational level should also be included in some of the discussions of adaptation, both to capitalize on their detailed knowledge of the systems and to create buy-in at all levels.

The group would also meet the need for continued and enhanced engagement with professional organizations, local universities, and other state-wide adaptation initiatives, such as the New York State Climate Action Council. Additionally, the group could develop checklists for field-level design and operation personnel to incorporate climate change adaptation in ongoing NYSDOT work. It would also provide special support for large capital projects such as the projected new Tappan Zee Bridge, and for pre-planning for emergency replacements such as the Lake Champlain Bridge. Further, it would encourage throughout the NYSDOT the organization and analysis of current regional data on storms, storm intensity, and icing. The projected life of the initial team, for which there should be adequate staff support, would be several years, until climate change adaptation is a regular input into NYSDOT activities. Thereafter, another group charged with oversight could be developed.

Training programs could also fall under the purview of this group, at least in part. From both the climate risk information discussions and other relevant sources, training could be provided in several areas of climate change adaptation:

- Climate science—sessions with outside scientists on the basic science, with an emphasis on the both the understanding of climate change as embodied in global climate models (GCMs), and the nature of uncertainty about future scenarios of climate change. All of the interviewees were conversant with climate change, and several had gone into the details of what is known scientifically in some depth; but more information should be made available to all managers.

- Future scenarios for current impacts that affect NYSDOT operations, such as heat, winds, and intense precipitation.

- Changing guidelines for NYSDOT design, construction and operations. These sessions could include representatives from engineering societies as well as engineering faculty from NYS and other universities.

- Adaptation assessment steps, including the integration of adaptation measures with capital and rehabilitation cycles, and the development of flexible adaptation pathways.

These sessions and others could ultimately be developed as webcasts or guidebooks; however, it is recommended that the first ones be in-person with NYSDOT groups of suitable size, in order to develop the training guidelines in the most effective way. Where possible, at least some of the sessions should focus on identifying points at which adaptation can be brought into current planning, design, implementation, and risk management practices in order to encourage the streamlining of adaptation into the NYSDOT.

5.5 Guidelines for planning documents: effective adaptation There is a growing body of adaptation planning guidelines and methods, such as those developed for the New York City Panel on Climate Change (NPCC, 2010) and the NYSCAC (2010) to provide a framework for the NYSDOT's evaluation of adaptation options as they relate to local, regional, social and environmental implications. Such evaluation would also include an assessment of opportunities to incorporate climate change under current environmental rules and regulations (Sussman and Major, 2010). An important part of evaluating alternative adaptations is to encourage flexible implementation along multiple, time-staggered decision paths. In this regard, guidelines could be developed in the near term to set target levels for certain types of projects that would trigger design reconsiderations even before the full implementation of NYSDOT's climate change adaptation programs. These guidelines could take the form, for instance, of identifying transportation infrastructure near coastal areas that is due for rehabilitation and is within a certain height of mean sea level (MSL). While much is now known about climate change, the development of guidelines will depend to some extent on additional research; recommendations are in NYSCAC (2010), NRC (2008, 2010) and NPCC (2010). NYSDOT can participate in writing nationally applicable transportation guidelines or standards to ensure that they contain adequate language and technical content for addressing climate change adaptation (and/or mitigation—NYSCAC, 2010, ch. 7).

Among documents that can be developed to begin the evaluation process are several inventories; some inventory procedures are described in Major and O'Grady (2010). (An overall model similar to the adaptation framework presented in Major and O'Grady, 2010, is the FHWA Vulnerability Risk Model, FHWA n.d.) There are already initiatives underway in the NYSDOT, such as a complete listing of culverts, on which such efforts can build.

- A digital data base of all NYSDOT "as built" structural and road bed elevations in coastal areas, at least to elevations –say- below 20 or perhaps even 30 ft above current sea level is necessary to make reasonable decisions based on projected

climate risks including storm surge and SLR. This information should be referenced to the latest vertical datum (currently NAVD 88).

- More generally, and using information on climate hazards such as that provided in this report and in Rosenzweig et al. (2011), it is essential to develop a full inventory of NYSDOT- owned transportation infrastructure at risk to these climate change hazards (and benefits where applicable) and a systematic assessment of the transportation systems' vulnerabilities to these hazards. (Jacob et al., 2011; Zimmerman and Faris, 2010).

5.6 Linkages to capital planning and rehabilitation cycles: efficient adaptation One of the most important elements of cost-effective climate change adaptation is incorporating adaptations into infrastructure during replacement and rehabilitation, rather than on an ad hoc basis (Major and O'Grady, 2010). All of the interviewees were fully engaged in the rolling 5 year capital plans used by the NYSDOT, and also cognizant of the 12 year plans that are developed from time to time and the 20 year State plans required by the Federal government. Integrating climate change adaptation into these plans can be an important part of budget proposals, demonstrating the commitment of an agency not only to effective but also efficient adaptation. There is a great deal of scope for this now with NYSDOT's activities. New York State ranks among the bottom 10 states in the nation for both highway and bridge conditions. The primary reasons are the system's age, heavy usage and the harsh northeastern climate. Of the State's bridges, for example, 6,625 – more than a third - are 50 years old, the expected useful life of a bridge. The bridges built during the Federal Interstate Highway construction era of the 1960s now fall into this category. Highways and bridges require continuing investment, as critical components of the system are reaching the end of their useful life. (NYSDOT 2009, p. 12) While this situation has negative connotations, at the same time it provides for opportunities for efficient adaptation to climate change if the NYSDOT inaugurates a suitable program in the near term.

Some specific mechanisms that can be used to encourage effective adaptation planning include MPO inputs to the statewide transportation plan, the Transportation Improvement Programs (TIPS) (on a 5 year cycle for development and 2 year renewals), the NYSDOT capital plan, maintenance and updating cycles, current updating mechanisms for standards, and any projects at stages where design protocols could be changed. NYSDEC permits and emergency operations are also an important area for more effective adaptation.

The overarching NYS Climate Action Plan (2010) and State Energy Plan, in which the NYSDOT participates, should be important driving forces for adaptation. To prepare the CAP, the Climate Action Council was created by Executive Order No 24, August 2009. It has several technical working groups, including the Adaptation Working Group (AWG). The AWG has eight sector subgroups, including one on transportation that included NYSDOT members. The recommendations developed for the NYSCAC provide important guidelines and inputs on climate change adaptation alternatives to the NYSDOT and other transportation agencies.

5.7 Keeping current with climate science and adaptation planning It is important for the NYSDOT to link to ongoing climate science and adaptation planning, through contacts with local, national and international organizations scientific and planning organizations. Adaptation plans should account for changes in climate science, impacts, technological advancements and adaptation strategies. There are regular advances in all these fields; the next substantial international evaluation of the entire field of climate change will be the IPCC report due in 4-5 years. The NYSCAC recommended that NYS adopt a consistent set of climate guidelines; these would then be adopted by NYSDOT. For more detailed information (e.g. on extreme events) as it becomes available, NYSDOT can make arrangements to obtain the pertinent climate information in the spatial and temporal (forward looking) resolution that will be needed to move ahead on mainstreaming from scientific institutions in New York State and elsewhere. These include the Goddard Institute for Space Studies; the Geophysical Fluid Dynamics Laboratory at Princeton (which, like Goddard, operates a GCM used in the IPCC forecasts); SUNY Stony Brook; Stevens Institute of Technology; Cornell University; and Columbia University's Earth Institute. The NYSDOT already uses data from local weather stations and other sources to plan for their operations, including winter road maintenance. Coordination with weather and climate service agencies would help to insure that climate data tracked by NYSDOT could be incorporated into databases maintained by the scientists to monitor the progress of climate change.

Monitoring and reassessment are critical components of any climate change adaptation plan. Monitoring relates both to climate indicators, such as extreme precipitation events, and climate impacts, such as shore erosion. Some monitoring will be directly relevant to NYSDOT adaptation planning, and other monitoring will be of a more general informational nature. Horton et al. (2011) provide details on monitoring. In addition to the indicators suggested here, others will likely become evident as climate changes and the need for adaptation planning develops.

Climate indicators of direct relevance to NYSDOT, and examples of how they relate to NYSDOT programs and facilities, include the following (see also NRC 2008, Annex 5-1A):

Sea-level rise and storm surge

- Average sea level (long-term impacts on coastal roads)
- High water levels (road and facility flooding)
- Extreme wind events (road closures and facilities damage)

Precipitation

- Extreme precipitation events (rapid inland flooding of roads and facilities), including coastal storms and Nor'easters

Temperature

- Average annual temperatures (potential impacts on buildings and materials
- Temperature extremes (impacts on work conditions [heat] and freezing conditions [cold])

Indicators that might be of great interest to NYSDOT, especially for long-term planning, that can be monitored without detailed special programs on the agency's part, include larger-scale climate indicators such as:

- Nor'easter frequency and intensity
- Tropical storms over the entire North Atlantic basin, as well as climatic conditions (including upper-ocean temperatures) that support tropical cyclones
- Variability patterns that influence the region, such as the North Atlantic Oscillation (large-scale ocean circulation patterns) and the El Niño Southern Oscillation climate pattern
- Status of ice sheets
- Changes in sea-ice area and volume
- Global and regional sea level
- Polar upper-ocean temperatures

Of these large-scale indicators, those relating to the ice sheets and potentially more rapid ice melt may be of most importance to NYSDOT long-term planning.

Climate variables cause climate-related impacts**,** which can also be monitored to help in shaping adaptation planning over the long term. These impacts include:

- Shoreline erosion
- Localized inland flooding
- Biological and chemical composition of waters
- Changes in vegetation

In addition to monitoring climate changes and their impacts, advances in scientific understanding, technology and adaptation strategies can also be monitored. Technological advances, such as those in materials science and engineering, could influence design and planning and potentially result in cost savings. Monitoring adaptation plans in the region should be done both to determine if they are meeting their intended objectives and to discern any unforeseen consequences of the adaptation strategies. Some adaptation strategies will also have to be reassessed in the context of non-climate factors that are based on uncertain projections. For example, by monitoring trends in population, economic growth and material costs, managers can tailor future climate change adaptation strategies to ensure they remain consistent with broader NYSDOT objectives.

Chapter 6: Communications and Technology Transfer Plan

6.1 Project Workshop.

The project description includes a workshop for NYSDOT managers designed to provide an overview of the project methods and results, and to consider next steps for the NYSDOT's climate adaptation programs. This workshop can take a variety of forms. One possible outline is given here.

Suggested NYSDOT Workshop Agenda with 2 Consecutive Sessions:

a. **Session I: 2.0 Hour Session for Executives and Practitioners**
b. **Session II:1.5 Hour Session for NYSDOT Practitioners**

Workshop Session I for Executives and Practitioners		
Topic	**Presenter**	**Length**
Welcome Remarks	NYSDOT Commissioner	5 min
Climate Change Projections for NYS	NYSDEC or NYSERDA	30 min
Overview of NYS Adaptation Activities: **-NYS Climate Action Council** **-Sea Level Rise Taskforce** **-Interagency Workgroup** Highlights and recommendations of the above studies.	Elisabeth Kolb & NYSDEC/NYSERDA	15 min
Introduction to the purpose and results of the project: "Mainstreaming Climate Change Adaptation Strategies into NYSDOT's Operations" Highlights of findings.	Dr. David Major	35 min
Executive Feedback to Findings Executive weigh-in on findings, recommendations and next steps.	NYSDOT Moderator	35 min
Adjourn Session I **and Break for Lunch** (on your own)	LUNCH	1 hr

Workshop Session II for Practitioners

Topic	Presenter	Length
Session II Welcome Remarks	Dr. John Zamurs	5 min
Linking climate impacts and vulnerabilities to future NYSDOT Activities. This session links the research studies related to climate impacts and vulnerabilities to transportation in NYS, especially as these relate to NYSDOT's responsibilities. The intention of this discussion is to integrate the climate science and the range of adaptations so that the NYSDOT can begin the complex process of evaluating adaptations as these are appropriate to the agency as a whole and to different regions and administrative divisions.	Dr. David Major	45 min
Identifying the barriers and opportunities for next steps within the NYSDOT, including organizational measures and staffing. An open discussion based on the project report and related studies to identify opportunities for moving ahead, and also identifying any institutional, financial, infrastructural, bureaucratic and other barriers to effective adaptation for climate change that should be considered in further developing climate change adaptation programs within the NYSDOT. Possible follow-on activities to assist in implementing the NYSDOT's long-term climate change adaptation response can be identified.	Prof. Zimmerman leading discussion with Practitioners	30 min
Q & A	NYSDOT Workshop Moderator	10 min
Adjourn		

6.2 Other suggested communications and technology transfer approaches
Following the project workshop, there is a range of other possible communications and technology transfer programs; three are described here.

6.2.1 Individual discussions with managers. Within the overall approach to climate change adaptation that is suggested in this document, there may be a need for individual or small group meetings between climate scientists and adaptation planners with the NYSDOT's managers. The reason for these meetings is that there is a very extensive range of questions and issues that could be explored in detail with managers without the constraints of time in larger meetings.

6.2.2 There could also be smaller workshops for personnel at all levels on climate change and adaptation. These latter could perhaps be follow-on activities for a later stage of the NYSDOT's climate change adaptation program. Such workshops were used successfully by the Columbia team in earlier work with the NYCDEP (Rosenzweig et al., 2007).

6.2.3 Webpage and webcasts. The development of webcasts could follow workshops as described in 6.2.1 and 6.2.2; the webcasts can then be tailored to the needs of NYSDOT personnel as a result of experience with in-person training sessions. The webpage will be primarily a NYSDOT effort, and should be developed as an internal tool initially on which climate-related inventories, scenarios, and design proposals can be posted and evaluated. Some of this material can be used as add-ons to the existing NYSDOT webpage for the public.

6.3 Program review and comment The current state of the NYSDOT"s adaptation programs, including participation in groups such as the NYS Climate Action Council, is one of forward movement, given the internal working groups that were established and the interest in climate change adaptation as evidenced by support for this report. The immediate challenge for the NYSDOT is to develop organizational and training efforts that will bring it to the level of recommendations and planned procedures in such documents as California (2009); NRC (2008, 2010); NPCC (2010); and others. These are achievable with a reasonable level of resources and the creation and strengthening of an institutional structure as proposed earlier. Beyond that, and achievable but more challenging, is the revision of design protocols and the actual implementation of staged adaptations as climate change progresses. It is with the latter work that the NYSDOT can be among the leaders of transportation agencies in dealing with climate change.

Appendix 1: Climate Risk Information Summary

(January 8, 2010)

Name of Division or Group:

Respondent(s):

Interviewer(s):

Date of interview:

Relevant Systems and System Aspects

1. As background for the questions on climate risk below, please note briefly the transportation systems (or key aspects, elements of systems, or facilities) with which your division or group is concerned. Systems are defined broadly, for example:

Road: NYS Highways; County & Local Roads; Authority Owned Highways and Bridges (i.e. NYS Thruway, Peace Bridge)

Rail: Commuter Rail (i.e. LIRR); Passenger Rail (Amtrak); Freight Rail (i.e. CSX)

Water: Passenger Service (i.e. NY Waterways); Freight Service (i.e. Port of Albany)

Air: NYSDOT operated Airports (i.e. Republic Airport); Other Commercial & General Aviation Airports

Other: Transit Systems (i.e. CDTA, MTA); Pedestrian and Bicycle Facilities; Intelligent Transportation Systems

For each system, does your group deal with a) the whole system, b) the whole system with emphasis on certain key aspects, elements, or facilities; or c) only certain key aspects, elements, or facilities?

This information will be recorded in a series of tables for Question 1, of which an example is given here. During the discussion there will be as many tables included digitally as are required for your group. (This approach will also be used for other questions that can be framed as matrices or tables.)

	System1:	System 2:
Full System		
System Operations		
Facilities Maintenance		
Demand Management/Pricing		
Emergency Management		

Long-term planning		
System financing		
Legal		
Public communications		
Other		
Comments		

Climate Impacts and Adaptation

2. What aspects of climate now (or are likely in the future to) affect each of the systems (or key aspects, elements of systems, or facilities) listed in Question 1 to a significant degree? How do (or will) these aspects of climate affect each of the systems listed in Question 1? What work has been done to assess these impacts? (Examples of such impacts are increased coastal flooding due to higher sea levels and storm surge, impacts on materials of higher temperatures, and drainage problems caused by more intense rainfall.)

The aspects of climate concerned are: Sea level rise, lake and river levels, storm surge, intense rainfall, winds, temperatures, and other. An example of the table for Question 2 answers is given here:

Sea Level Rise

	Impacts	Nature of Impacts	Assessment of impacts underway	No work done as of yet
System 1:				
System 2:				

3. Has work been done thus far to consider operations/management, infrastructure investment, and/or policy adaptations to climate change for the systems (or key aspects, elements of systems, or facilities) that your group/division manages/oversees? Operations/management examples include: development of plans for more flexible rerouting under severe conditions; an example of infrastructure investment example is flood walls; an example of policy is cooperation with other agencies to increase system resiliency. An example of the table for Question 3 answers is given here:

Operations/management

System	No work done as yet (specify reason)	Some work done (specify)	Substantial work done (specify)
System 1:			

4. Many agencies have existing programs to deal with extreme events and other elements of climate that can be extended to deal with climate change. Please identify any such programs that relate to the work of the group or division providing information for this report in the categories of operations/management, infrastructure investment, and/or policy. Examples include rail traffic rerouting under storm conditions, structural elements to protect against high winds, and road closures due to flooding. An example of the table for Question 4 answers is given here:

Operations/management

System	No programs currently identified	Yes, these programs include:
System 1:		

System Ownership and Control

5. With respect to each of the systems listed in Question 1, does the NYSDOT: own and operate; own only; operate only; regulate; contribute financing only; other?
For example, NYSDOT might own, operate and regulate the use of roadways, but the vehicles that use them are privately owned. An example of the table for Question 5 answers is given here:

	System 1:	System 2:
Own and operate		
Own only		
Operate only		
Regulate		
Contribute financing only		
Other		

6. For systems that NYSDOT owns and operates:

A. What regulatory authorities exercise significant control over system design and operation? An example of the table for Question 6 answers is given here:

	System 1:	System 2:
Federal		
State		
Municipal		

Other (e.g. regional)		

B. What laws, regulations, permits, guidance, etc. govern the actions of these authorities with respect to the relevant transportation systems?

C. Do these authorities require consideration of climate change in NYSDOT systems? (Adaptations are measures taken to respond to the impacts of climate change.)

7. For systems that NYSDOT does not own and operate:

A. With which entities is decision-making authority shared? An example of the table for Question 7 answers is given here:

	System 1:	System 2:
Federal		
State		
Municipal		
Other (e.g. regional)		

B. What laws, regulations, permits, guidance, etc. govern the actions of these authorities with respect to the relevant transportation systems?

C. Do these authorities require consideration of climate change in NYSDOT systems?

Capital Planning

8. With respect to each system listed in Question 1, what capital replacement and rehabilitation schedules are in effect that might relate to future climate change adaptations?

	System 1:	System 2:
Federal		
State		
Municipal		
Other (e.g. regional)		

9. With respect to these capital replacement and rehabilitation schedules;

A. How easily can these be modified to take climate change adaptations into account?

a.. Easily adapted
b. Complex to adapt

B. What measures would be required to make those changes?

a. Changes in internal procedures
b. New or amended legal authorities
c. Other

Additional Information and Suggestions

10. Are there additional plans (other than the present study) to further consider climate change in your group/division?

a. Yes (specify)
b. No

11. What topics would you like to see included in the project workshop?

Thank you!

Appendix 2: Literature Review Methodology

Overview of the Literature Review

The literature review carried out for the project has several aspects. The material in the report on climate and vulnerability (Chapters 2 and 3) is based on already substantial literature reviews. In the literature review carried out specifically for this project, additional references, including recent work, have been added to these chapters. Tthe main results of the literature review are presented in Chapter 4, dealing with adaptation strategies and best practices. The results of the literature review also impact Chapters 5 and 6.

Summary/Findings:

There is a significant amount of research and literature on the vulnerabilities and hazards associated with climate change and the transportation sector; however, only a relatively small part of this literature deals with the actual design and implementation of climate change adaptations. Most recommendations are based on a general discussion of the need for adaptation; a small number of reports discuss specific strategies for transportation adaptation. Within that smaller group, some highlight actual adaptation efforts, including institutional arrangements and planning. Some federal and state reports discuss transportation planning and renovation efforts founded on adaptations to climate variability; some of these can be interpreted as relevant to climate change as well. Overall, within federal, state and local climate change reports, the most abundant finding was the acknowledgement of the lack of actual transportation adaptation efforts and research. Many reports discussed the need for more research, and some recommended possible future areas of study within the transportation infrastructure field.

Research:

1. *Initial review* (several hundred reports): This stage included a broad search for climate change adaptation reports, including federal, regional, state and local assessments.
2. *Preliminary assessment* (approx. 100 reports): During this stage, reports were reviewed for transportation-specific discussions of adaptation. General themes and search topics included:
    a. Identification of vulnerabilities and hazards within transportation infrastructure as a result of climate change
    b. Climate change adaptation as an extension of transportation risk management
    c. Transportation adaptation strategies, plans and timelines
    d. Coordination of adaptation plans, including shared and overlapping infrastructure
    e. Budget planning for transportation adaptation goals
3. *Comprehensive assessment* (19 reports): This stage included a comprehensive assessment and categorization of the most expansive transportation adaptation reports. During this stage, summaries of the reports were drafted, including an

analysis and breakdown of specific topics addressed. This assessment includes reports categorized as "strategies," "institutional" and "actual," excluding the categories of "discussion" and "vulnerabilities."

Literature Categories:

1. *Discussion*: Report acknowledges or includes a discussion on the need for transportation adaptation to climate change
2. *Vulnerabilities*: Report primarily discusses vulnerabilities and impacts of climate change to transportation infrastructure
3. *Strategies*: Report outlines strategies for transportation adaptation, including infrastructure-specific adaptation strategies or future adaptation goals
4. *Institutional*: Report discusses institutional measures adopted within transportation sectors dealing with climate change adaptation
5. *Actual*: Report details existing adaptations to climate change within the transportation sector

Sub-Categories:

1. *Roads/Bridges*: Report focuses or includes a discussion of road and bridge-specific adaptation measures or strategies
2. *Federal, State, Local, Regional, General*: Distinctions were made between the scope of the report
3. *Cost Analysis*: Report includes a discussion of economic costs associated with transportation adaptation.
4. *Case Studies*: Report analyzes specific regions or infrastructure with respect to adaptation efforts.
5. *Planning*: Report details short and long-term adaptation planning efforts being made.
6. *Design standards*: Report includes a discussion of the need to alter design standards as an aspect of transportation adaptation methods.

Sources:

1. Expert sources: New York, California, Canada, Oregon
2. Transportation Research Board
    a. Search terms: climate change, climate change adaptation, transportation planning
3. Pew Center on Global Climate Change:
    a. "Table 1: State Adaptation Planning Efforts"
    b. "Table 2: State Climate Action Plans"
    c. "City/County Adaptation Planning"
4. US DOT: Transportation and Climate Change Clearinghouse
5. Selected Additional Lists of Climate Change Studies and Reports from original NYSDOT RFP and Columbia proposal
6. *Preparing for Climate Change: A Guidebook for Local, Regional and State Governments*
    a. "D: Sources of Information on Climate Change Impacts and Adaptation"

b. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

7. Other: New York State Climate Action Council, 2010. *Interim Report*, November 9, 2010; FHWA Vulnerability Risk Model Pilot Study http://www.fhwa.dot.gov/hep/climate/conceptual_model62410.htm

Summaries of Selected Key Documents

Andrey, J., and Christopher Knapper, 2003, *Weather and Transportation in Canada*. Department of Geography Publication Series. C. Mitchell, University of Waterloo. Key Adaptations and Associated Costs: (p. 255-268).
http://ersserver.uwaterloo.ca/research/GeogPubs/pdf/transportation_andrey01.pdf#page=251
Category: strategies/actual
Includes: cost analysis, case studies
p. 255-67:

This section includes several references to estimated economic costs associated with climate change adaptation within the Canadian transport sector, claiming that $1.7 billion is spent annually in adapting to current climate conditions. The report includes several specific adaptation measures based on various climate change projections, including increases in freeze-thaw cycles and increased summer temperatures. It also discusses existing adaptation measures throughout Canada, highlighting measures for the capture of drifting snow, rainwater drainage and elevating bridge heights as a result of sea level rise. Specifically, the report addresses adaptation measures in Ontario, the Cobequid Pass, the Confederation Bridge, Highway 99 in British Columbia, and the B.C. Rail line.

Asian Development Bank, 2005, *Climate Proofing: A Risk-based Approach to Adaptation*. Pacific Studies Series.
http://www.adb.org/Documents/Reports/Climate-Proofing/chap6.pdf
Category: strategies
Includes: cost analysis
Chapter VI: D. Case Study One: Climate Proofing a Roadbuilding Infrastructure Project in Kosrae, Federated States of Micronesia (p. 26-32):

This case study examines the roadbuilding development plan for Kosrae, specifically a 9.8-km unbuilt portion of the circumferential road north of the Yela Valley. The chapter details a climate-proofed design plan for the road design, including construction, maintenance and repair costs for the built and unbuilt sections of the road. The chapter also analyzes the cost differences between initial climate-proof construction and retrofitted adaptation efforts, concluding that it is more costly to climate proof retroactively. However, the Kosrae state government decided not to proceed with construction of the road until additional funds were available for climate proofing.

Brown, J. L., 2005, "High-Altitude Railway Designed to Survive Climate Change." *Civil*

Engineering 75(4): 28-28.
Category: actual
Includes: case study
p. 28:

This article discusses the construction of a permafrost cooling system for the Qinghai-Tibet Railway, which protects the railway infrastructure from permafrost-related damages as a result of temperature rise.

California Natural Resources Agency, 2009, *California Climate Adaptation Strategy*. http://www.climatechange.ca.gov/adaptation/
Category: strategies
Includes: planning, vulnerabilities
10: Transportation and Energy Infrastructure (p.129-134)

This chapter includes a report on infrastructure adaptation strategies, specifically those that apply to the transportation sector. These strategies include developing a climate vulnerability assessment and adaptation plan, incorporating climate change vulnerability tools into existing transportation and investment decisions, developing design and engineering standards to minimize risks to vulnerable transportation infrastructure, and incorporating climate change impacts into disaster preparedness. The proposed strategies include which California government agencies will address specific aspects of adaptation, as well as key development phases throughout the process.

Eddowes, M.J., Daniel Waller, Peter Taylor, Brian Briggs, Tricia Meade, Iain Ferguson, 2003, *Railway Safety Implications of Weather, Climate and Climate Change: Final Report*. Rail Safety & Standards Board, United Kingdom. http://www.rssb.co.uk/pdf/reports/research/Safety%20implications%20of%20weather,%20climate%20and%20climate%20change.pdf
Category: strategies
4.3.3: Adaptation Strategies (p.32-33)

This section includes seven brief suggestions for transportation adaptation to climate change strategies, including improvements in flood defenses, restrictions on development, use of more durable materials, improving drainage systems along highways and railways and the use of low maintenance vegetation as buffer zones.

7.1: Rail Industry Involvement in Climate Change Impacts Research (p.55-57)

This section does not discuss adaptation, but does address possible strategies for institutional adaptation research and involvement, such as incorporating the railway industry into the UK Climate Impacts Programme (UKCIP).

Gallivan, F., Kathleen Bailey, Laurence Matthew O'Rourke, 2009, *Planning for Impacts of Climate Change at U.S. Ports*. U.S. Environmental Protection Agency.
Category: strategies

This article provides an overview of existing climate change adaptation efforts and current state of practice at ports in the United States. It refers to the existing

policy of deterministic transportation planning, rather than the use of risk assessment as a method of adaptation. The article addresses the difference of timeframes between existing ports and general climate projections, and how this causes difficulty in transportation adaptation planning. Lastly, the article also proposes five ideas for possible action within U.S. port adaptation.

Hogan, D., 2008, *Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure*. Canadian Council of Professional Engineers.
http://www.pievc.ca/e/doc_list.cfm?dsid=4
Category: strategies
Includes: roads/bridges, vulnerabilities, case studies
Chapter 8: Roads and Associated Structures

This report provides an assessment of the climate change vulnerabilities to specific modes of transportation in Canada, from an engineering perspective. It provides case studies, in which specific recommendations are made for adaptation within the transportation infrastructure.

Appendix B-2: Town of Placentia, Newfoundland

This case study analyzes the town of Placentia, Newfoundland, and provides a list of region-specific recommendations for adaptation to climate change within the transportation sector. The recommendations are specific to the categories of capacity, stability, maintenance, operations and monitoring, property protection, policies and procedures, and lifestyle planning.

Appendix B-4: City of Greater Sudbury, Ontario

This appendix studies the city of Greater Sudbury, Ontario, and includes a diagram that outlines specific recommendations for transportation infrastructure, based on an assigned level of vulnerability.

Appendix B-5: Quesnell Bridge, City of Edmonton, Alberta

This case study focuses on the Quesnell Bridge in the city of Edmonton, Alberta. It provides bridge-specific recommendations for climate change adaptation, including strategies for the deck system, freeze-thaw dynamics, ice accretion and drainage systems.

Ireland, Republic of, National Roads Authority, 2008, "Road owners getting to grips with Climate Change." Strategic Research Opportunity 3. (ongoing).
http://www.eranetroad.org/index.php?option=com_content&view=article&id=76&Itemid=79
Category: Institutional
Includes: Roads/Bridges

This ongoing project is sponsored by the National Roads Authority, and aims to "evaluate the effect of climate change on the road network and take remedial action through all components of road management including design, construction and maintenance." The project includes four commissioned projects that focus on storm water prevention, risk management, pavement performance and local road winter indexes.

Jacob, K., George Deodatis, John Atlas, Morgan Whitcomb, Madeline Lopeman, Olga Markogiannaki, Zackary Kennett, Aurelie Morla, Radley Horton, Daniel Bader, Robin Leichenko, Peter Ventura and Yehuda Klein, 2011, "Transportation Infrastructure." *NYS ClimAID*. Note: this summary is based on the 2010 final draft of this document; final publication came after the completion of this report.
Category: strategies

5.9: Social Justice and Adaptation

This section addresses the possibility of socially selective hardening of transport infrastructure as a result of short-term and long-term adaptation.

5.10: Coastal-Storm-Surge Adaptation Options, Adaptation Strategies, and their Policy Implications

This section details several short-term, medium-term and long-term strategies. It also includes a list of suggested time-dependent assessments for current and projected conditions.

6: Statewide Transportation Adaptation Strategies

This section discusses different adaptation options based on a variety of geographical, land-use and climate zones within the state. It addresses the roles that transportation agencies should play in adaptation, as well as cooperation within agencies. It also includes a list of technical and procedural tasks needed to pursue adaptation projects.

6.1-6.5:

These sections analyze specific options for adaptation to various types of climate change, including coastal hazards, heat hazards, precipitation hazards, winter storms and other extreme events.

*8. Findings and Recommendation*s:

This chapter develops specific options for adaptation within the transportation sector in the state of New York. It is structured in a findings-recommendation format.

Jacob, K., Cynthia Rosenzweig, Radley Horton, David Major, and Vivien Gornitz, 2008, *MTA Adaptations to Climate Change*. Lamont-Doherty Earth Observatory and Center for Climate Systems Research, Columbia University.
http://www.mta.info/sustainability/pdf/Jacob_et%20al_MTA_Adaptation_Final_0309.pdf
Category: strategies
Includes: planning, vulnerabilities, case study

This report provides an extensive adaptation strategy that is geared specifically to the MTA in New York City. It includes an adaptation plan, highlights possible climate change scenarios, challenges and vulnerabilities as they relate to the transportation sector, as well as provides findings and recommendations for adaptation. Suggestions are made for short-term and long-term adaptation plans, and specific adaptation techniques are provided for each hazard's vulnerabilities.

King County, 2007, *King County Climate Plan, 2007*. King County, Washington.
http://your.kingcounty.gov/exec/news/2007/pdf/climateplan.pdf
Category: institutional

Includes: roads/bridges
B: Adaptation (p. 110-120)

This report identifies focus areas in which adaptation strategies can be implemented in King County, Washington, including transportation. One of the strategic goals of the overall climate adaptation plan is to "protect the integrity and safe operation of regional transportation infrastructure from climate change impacts," including the incorporation of climate change impacts information into construction, operations and maintenance of infrastructure projects and training road services division staff in climate change impacts (Strategic Goal, p.118) The report provides specific suggestions for implementing climate change adaptation education, planning and design into the transportation sector, including specific documents and policies that would be updated. The report also offers strategies for physical infrastructure, including bridge maintenance, storm water flow control, seawall modification, alternative transportation routes, etc.

Lee, R., 2000, *Climate Change and Environmental Assessment: Part 1: Review of Climate Change Considerations in Selected Past Environmental Assessments*. Research and Development Monograph Series, The Canadian Institute for Climate Studies. http://www.ceaa.gc.ca/default.asp?lang=En&n=F2F22AF3-1
Category: actual
Includes: roads/bridges
Appendix D. Confederation Bridge (Fixed Link – Northumberland Straight Crossing):

This appendix provides a chronological review of the climate change considerations incorporated into the construction of the Confederation Bridge. The appendix outlines specific bridge design changes that were made in order to accommodate sea level rise and ice-out events as a result of climate change. The appendix also describes the process of federal governmental intervention, assessment, and implementation of global warming considerations, which eventually led to the bridge's capability to withstand a 1-meter sea level rise during its lifetime.

Lemmen, D.S., F.J. Warren, J. Lacroix and E. Bush, 2008, *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada, Ottawa, Ontario. http://adaptation.nrcan.gc.ca/assess/2007/index_e.php
Category: actual
Includes: roads/bridges, institutional efforts, design standards
3: Northern Canada (p. 82-87)

This section discusses specific results of climate change on the transportation infrastructure in northern Canada. It addresses opportunities for economic growth as a result of longer summer ice-free seasons, changes in marine traffic routes, freshwater transport and winter roads. The discussion of transportation adaptation is interwoven within the discussion of impacts, but specific strategies for regionally based adaptation are not provided for each method of transportation. Long-term and short-term adaptation strategies, as well as their effects, are considered.

4: Atlantic Canada (p. 151-153)

This section describes current transportation infrastructure efforts to adapt to the effects of climate change, including impacts to road systems, marine transport, rail and air transport. The section outlines various projects that are currently being done in response to sea level rise, storm events and changing durations of winter seasons. It also offers several suggestions for provincial-level transportation adaptation plans, including identification of key facilities or locations that may be impacted, assessing resiliency of infrastructure, as well as changes to maintenance and safety procedures.

5: Quebec (p. 200)

This section discusses the increasing complexity in managing transportation infrastructure as a result of climate change. It also highlights several existing methods of adapting to climate change impacts in Quebec, such as winter maintenance decision support systems and fixed or mobile instrumentation of weather technologies. It also provides several suggestions for general infrastructure adaptation, including the need to revise design criteria and standards, establish improved emergency measures, set up communication networks, re-examine land-use planning policies and regulations and develop preventative warning systems. While these strategies are not specific to the transportation sector, they are specific to the built infrastructure sector, in which transportation is included.

6: Ontario (p. 261)

This section highlights existing adaptive measures within the transportation sector such as accelerated conversion of granular roads to tar and chip roads. Also, methods of future transportation infrastructure adaptation are suggested, including reducing the weight carried per ship, dredging connected channels and ports, modification in ice road construction and changes in maintenance and reconstruction of facilities.

7: Prairies (p. 303-306)

This section discusses the need for improvements to various aspects of the transportation infrastructure in the Prairies, such as improvements to storm-water management systems, consideration of changing transportation safety issues, and reduction of transportation costs associated with non-ice road and railway infrastructure. It also provides a case study on winter roads in northern Manitoba, which includes several community-based adaptation suggestions as a result of degrading winter roads.

Mehrotra, S., Benoit Lefevre, Rae Zimmerman, H. Gercek, K. Jacob, S. Srinivasan, 2011, Climate Change and Urban Transportation Systems. In *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network* (Cambridge University Press), ch. 6. Note: this assessment is based on a final draft of this chapter; final publication came after the completion of this review.

Category: strategies

Includes: vulnerabilities

6.2: Risk management as a framework for adaptation and mitigation

This section is a general discussion of adaptation as a form of risk management. It addresses the mismatch between perceived and actual risk as an obstacle to the

implementation of adaptation plans. This section also discusses an engineering and performance standards approach to adaptation.

6.3.1: Defining climate risks and methods of risk assessment

This section discusses vulnerability, fragility, probability of failure and states of damage in relation to climate risk. It also mentions the calculation of total annualized loss to a city's transportation system, and the importance of this analysis for the implementation of preventative measures.

6.4: *Adaptation of urban transportation systems*

This section discusses the need to mainstream adaptation through existing assets and planned investment. It also focuses on the need for an adaptation plan that considers all available options to the community, as well as costs and benefits to adaptation.

6.4.2: *Specific adaptation measures*

This section details specific techniques for retrofitting existing infrastructure that is susceptible to climate change, including incorporating climate projections into transportation projects, policy measures, modifying land-uses.

6.4.3: *Policy and economic consideration for adaptation*

This section discusses the role of local authorities in the coordination of changing land-use and transport systems, the need for city-specific adaptation assessments and also for long-range public transportation planning.

6.6.1: *Matrix approach:*

This section addresses the need for inclusion of policy instruments in the implementation of adaptation and mitigation plans.

Annex 1: Table 1 Direct impacts of climate change on transportation

National Research Council, Committee on Climate Change and U.S. Transportation, 2008, *Potential Impacts of Climate Change on U.S. Transportation*. Transportation Research Board Special Report 290, Washington, D.C.
http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf
Category: strategies
Includes: case studies, planning

5: Meeting the Challenges: Adaptation Strategies (p. 149-158)

This section analyzes a range of adaptation strategy possibilities, including possible operational responses to increased weather conditions as a result of climate change, improving the efficiency of transportation management centers, and reevaluation and development of existing infrastructure design standards. This section also addresses a case study in transportation adaptation within New Zealand transit.

New Infrastructure Investment, Transportation Planning, and Controls on Land Use (p. 158-163)

This section addresses adaptation as an extension of risk management, land use planning, and cooperation between land use decision-makers as well as planners. It also includes an explanation of scenario analysis within transportation planning as a strategy for incorporating climate change into the transportation planning process.

Crosscutting Issues: (p.163-172)

This section explains how flood insurance policies, monitoring technologies, data systems, and organizational arrangements are necessary for successful transportation adaptation.

Annex 5-1A—5-1C: Potential Climate Changes, Impacts on Land Transportation, and Adaptation Options

These annexes examine specific transportation adaptation strategies in a climate change-specific and infrastructure-specific organization. Separated by various climate change events, the annex includes specific adaptation options for highways, rail, pipeline, marine, and aviation transportation infrastructures.

Savonis, M. J., Virginia R. Burkett, and Joanne R. Potter, 2008, *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I*. Washington, DC, USA, U.S. Climate Change Science Program, Synthesis and Assessment Product 4.7, U.S. Department of Transportation.
http://www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf
Category: strategies
Includes: roads/bridges, case study

4.2: Climate Impacts on Transportation Modes (p. 15-48)

While this section primarily discusses the impacts of climate change on transportation infrastructure, it also mentions current adaptation methods being used to cope with impacts. The section is not directed toward adaptation, but presents many references to current adaptation methods being used in the Gulf Coast. This section is also broken up into the effects of each climate element on specific transportation sectors, including the private and public sectors.

4.3.3: Elevating Louisiana Highway 1 (p. 55)

This section briefly explains the process and importance of rebuilding the Louisiana Highway 1, but does not focus on this process as an element of adaptation.

5.0: How Can Transportation Professionals Incorporate Climate Change in Transportation Decisions (p. 1)

This chapter discusses long-range planning and investment as well as system evaluations of infrastructure within the process of development and renewal of transportation infrastructure.

5.1.3: Challenges and Opportunities to Integrating Climate Information (p. 13-16)

This section discusses the incorporation of climate change considerations into the transportation planning process, including timeframes, land use and institutional arrangements.

5.2: Conceptual Framework for Assessing Potential Impacts on Transportation (p. 16-26)

This section provides a conceptual approach to "how climate concerns might be addressed in a transportation context." Specifically, it addresses the inclusion of risk and uncertainty in transportation planning.

5.2.1: Factors of Concern: Exposure, Vulnerability, Resilience, and Adaptation (p.5-17—5-21)

This chapter uses an exposure to climate stressors, vulnerability, resilience, and adaptation model to propose a framework for including climate concerns in transportation planning. It discusses adaptation as a "decision that officials can

make in response to perceptions or objective measurement of vulnerability or exposure." Also, it proposes an adaptation strategy framework of protection, accommodation and retreat.

5.2.2: Framework for Assessing Local Climate Change Impacts on Transportation (p. 21-25)

This section explains how climate change/variability can be integrated into existing transportation policy within the context of adaptation. It makes suggestions for what types of data and policy recommendations are needed to lead to capital, maintenance or operational improvements in the transportation sector. It also discusses methods of incorporating risk assessment, rather than deterministic methods, into transportation decisions as an aspect of adaptation.

Titus, J., 2002, "Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?" *The Potential Impacts of Climate Change on Transportation*, The DOT Center for Climate Change & Environmental Forecasting.
http://epa.gov/climatechange/effects/downloads/Transportation_Paper.pdf
Category: strategies
Includes: case studies

Transportation Adaptive Responses to Sea Level Rise (p .5-15):

This article outlines several response strategies for transportation infrastructure adaptation, including elevating land structures, protecting with dikes, and retreat and accommodation methods. References are made to specific infrastructures, including the Prince Edward Island causeway, highways US-64 and US-264, and the cities of Kitty Hawk and Elizabeth, North Carolina.

p. 7: *Air, Rail, Shipping, Tunnels*

> *"Just as roads can be elevated, so can runways and railroad beds. New bridges and tunnels can be built higher than would otherwise be the case. For example, recognizing the logic of anticipating sea level rise, the designers of the new causeway to Prince Edward Island made it one meter higher than it would otherwise have been."*

United Kingdom, The Highways Agency, Transport Scotland, Welsh Assembly Government, The Department for Regional Development Northern Ireland, 2006, *Design Manual for Roads and Bridges, Surface and Sub-Surface Drainage Systems for Highways*, 4, Geotechnics and Drainage.
http://www.standardsforhighways.co.uk/dmrb/index.htm
Category: actual
Includes: design standards

Volume 4; Section 2; Part 3; Chapter 6:

The geotechnics and drainage volume of this design manual includes an adaptation strategy for increased rainfall intensities, stating:

> *"The rainfall intensities used to calculate the design storms must include an allowance for the effects of climate change. Where rainfall data exclude such an allowance, a sensitivity test on the design of the drainage system must be carried out by increasing rainfall intensities of the design storm by 20%."* (sec. 6.3)

Zimmerman, R., 2002, "Global Climate Change and Transportation Infrastructure: Lessons from the New York Area." *The Potential Impacts of Climate Change on Transportation*, The DOT Center for Climate Change & Environmental Forecasting. http://climate.dot.gov/documents/workshop1002/zimmermanrch.pdf
Category: strategies
Adaptation (p.6-8):

> This article outlines several generic adaptation strategies that are applicable to transportation planning, design, and management. Also, the article discusses the need for building institutional adaptation capacity, specifically as an extension of inter-organizational coordination and accommodation.

Appendix 3: Technical Working Group And Advisory Working Group Members

NYSDOT TECHNICAL WORKING GROUP

O. (Sam) A. Elrahman, Ph.D., Project Manager
Arthur Sanderson, P.E.
Pratip Lahiri, P.E.
Darrin Moret
Lisa Pelcher

COLUMBIA UNIVERSITY ADVISORY WORKING GROUP

William Solecki, Ph.D., co-Chair
Rae Zimmerman, Ph.D., co-Chair
John Falcocchio, Ph.D.
Radley Horton, Ph.D.
Klaus Jacob, Ph.D.
Cynthia Rosenzweig, Ph.D.

References

Asian Development Bank. 2005. Climate Proofing: A Risk-based Approach to Adaptation. Pacific Studies Series. http://www.adb.org/Documents/Reports/Climate-Proofing/chap6.pdf

California Department of Transportation. 2009. "Vulnerability of Transportation Systems to Sea Level Rise, Preliminary Assessment."

Charlson, Robert J. 1998. "Direct Climate Forcing by Anthropogenic Sulfate Aerosols: The Arrhenius Paradigm a Century Later." In *The Legacy of Svante Arrhenius. Understanding the Greenhouse Effect*, edited by Henning Rodhe and Robert Charlson. Stockholm: Royal Swedish Academy of Sciences. Pp. 59-71.

Church, J.A. and others. 2008. "Understanding global sea levels: past, present, and future." *Sustainability Science* 3:9–22.

Clarke, Simon, Jim Kersey, and Emily Trevorrow. 2002. *A Climate Change Impacts in London Evaluation Study.* London Climate Change Partnership.

Cornell University, New York State Climate. http://nysc.eas.cornell.edu/climate_of_ny.html

Costanza, R., M. Wilson, A. Troy, A. Voinov, S. Liu, and J. Agostino. 2006. *The Value of New Jersey's Ecosystem Services and Natural Capital.* Rubenstein School of Environment and Natural Resources, University of Vermont: Gund Institute for Ecological Economics. Burlington, VT.

Donnelly, J. P., Cleary, P., Newby, P., and Ettinger, R. 2004. "Coupling instrumental and geological records of sea-level change: Evidence from southern New England of an increase in the rate of sea-level rise in the late 19th century." *Geophysical Research Letters, 31*(5).

Eddowes, M.J., Daniel Waller, Peter Taylor, Brian Briggs, Tricia Meade, Iain Ferguson. 2003. *Railway Safety Implications of Weather, Climate and Climate Change: Final Report*. United Kingdom: Rail Safety & Standards Board.

Federal Highway Administration (FHWA) Vulnerability Risk Model Pilot Study. http://www.fhwa.dot.gov/hep/climate/conceptual_model62410.htm

Gallivan, F., Kathleen Bailey, Laurence Matthew O'Rourke. 2009. *Planning for Impacts of Climate Change at U.S. Ports*. U.S. Environmental Protection Agency.

Gehrels, W. R., Kirby, J. R., Prokoph, A., Newnham, R. M., Achertberg, E. P., Evans, H., et al.. 2005. "Onset of recent rapid sea-level rise in the western Atlantic Ocean." *Quaternary Science Reviews 24*(18-19). 2083 - 2100.

Goodman, Alvin S., and Makarand Hastak. 2006. Infrastructure Planning Handbook: Planning, Engineering, and Economics. ASCE Press.

Groisman, P.Y., R.W. Knight, T.R. Karl, D.R. Easterling, B. Sun, and J.H. Lawrimore. 2004. "Contempory changes of the hydrological cycle over the contiguous United States, trends derived from in situ observations." *Journal of Hydrometeorology* 5 (1). 64 - 85.

Hamilton, R. S., D. Zaff, and T. Niziol. 2007. "A catastrophic lake effect snow storm over Buffalo, NY October 12–13, 2006." presented during the 2007 American Meteorological Society's 22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction. ms.confex.com/ams/pdfpapers/124750.pdf.

Hayhoe, K. 2007. "Past and future changes in climate and hyrdological indicators in the US Northeast." *Climate Dynamics* 29: 381 - 407.

Holgate, S. J., and Woodworth, P. L. 2004. Evidence for enhanced coastal sea level rise during the 1990s. *Geophysical Research Letters, 31,* doi:10.1029/2004GL019626.

Horton, Radley and Cynthia Rosenzweig, Lead Authors, with Vivien Gornitz, Daniel Bader, and Megan O'Grady. 2010. "Climate Risk Information." In New York City Panel on Climate Change. *Climate Change Adaptation in New York City: Building a Risk Management Response.* C. Rosenzweig and W. Solecki, eds. New York: New York Academy of Sciences, Annals of the New York Academy of Sciences, Vol. 1196. Appendix A.

Horton, R., D. Bader, L. Tryhorn, A. DeGaetano, and C. Rosenzweig. 2011. "Climate Risks." In Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn, eds. *Responding to Climate Change in New York State*: *The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Technical Report. New York State Energy Research and Development Authority (NYSERDA). Albany, New York. Chapter 1

Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Ireland, Republic of, National Roads Authority. 2008. "Road owners getting to grips with Climate Change." *Strategic Research Opportunity 3.* (Ongoing).

Jacob, Klaus, Cynthia Rosenzweig, Radley Horton, David Major and Vivien Gornitz. 2008. *MTA Adaptation to Climate Change: A Categorical Imperative.* New York: MTA. October.

Jacob, Klaus**,** George Deodatis, John Atlas, Morgan Whitcomb, Madeleine Lopeman,

Olga Markogiannaki, Zackary Kennett, Aurelie Morla, Robin Leichenko and Peter Ventura "Transportation." 2011. In Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn, eds. *Responding to Climate Change in New York State*: *The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. Chapter 9.

King County, Washington. 2007. *King County Climate Plan, 2007*.

Kunkel, K.E., Westcott, N.E., Kristovich, D.A.R. 2002. "Assessment of potential effects of climate change on heavy lake-effect snowstorms near Lake Erie." *J. Great Lakes Res*, 28. 521–536.

Lee, Rick. 2000. *Climate Change and Environmental Assessment: Part 1: Review of Climate Change Considerations in Selected Past Environmental Assessments*. The Canadian Institute for Climate Studies,

Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., eds. 2008. *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ottawa, ON: Government of Canada.

Lim, Bo, and Erika Spanger-Siegfried, eds., co-authored by Ian Burton, Elizabeth Malone, and Saleemul Huq. 2005. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. Cambridge, UK: Cambridge University Press.

Lindquist, Eric. 2007. "Climate Change and Adaptive Strategies in Sub-National Transportation Planning Agencies in the United States." Prepared for presentation at the 2007 Amsterdam Conference on the Human Dimensions of Global Environmental Change. College Station TX: Institute for Science, Technology and Policy. Texas A&M University.

Major, David C. and Megan O'Grady, Lead Authors. 2010. "Adaptation Assessment Guidebook."In New York City Panel on Climate Change. *Climate Change Adaptation in New York City: Building a Risk Management Response*. C. Rosenzweig and W. Solecki, eds. New York: New York Academy of Sciences. Annals of the New York Academy of Sciences, Vol. 1196. Appendix B.

McCulloch, Martha M., Donald L. Forbes, Roderick W. Shaw, and the CCAF A041 Scientific Team. 2002. *Coastal Impacts of Climate Change and Sea-Level Rise on Prince Edward Island: Synthesis Report.* Geological Survey of Canada. Open File 421.

Meyer, Michael D. 2008. *Design Standards for U.S. Transportation Infrastructure: the Implications of Climate Change*. Atlanta GA. Georgia Institute of Technology.

Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer. 2008. "Climate Change: Stationarity Is Dead: Whither Water Management?" *Science* 1 February: 573-574.

Metropolitan Transportation Authority. n.d. *Greening Mass Transit and Metro Regions: A Synopsis of the Final Report of the Blue Ribbon Commission on Sustainability and the MTA*. http://www.mta.info/sustainability/pdf/synopsis.pdf.

Metropolitan Transportation Authority, http://www.mta.info/

Multihazard Mitigation Council. 2005. *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities*, vol. 2: Study Documentation. Washington DC: National Institute of Building Sciences.

National Research Council. Committee on Climate Change and U.S. Transportation. 2008. *Potential Impacts of climate change on U.S. transportation*. Transportation Research Board Special Report 290. Washington, DC: Transportation Research Board.

National Research Council, Panel on Adapting to the Impacts of Climate Change, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies. 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, Washington, DC: The National Academies Press.

New York City Panel on Climate Change. 2010. *Climate Change Adaptation in New York City: Building a Risk Management Response*. C. Rosenzweig and W. Solecki, eds. New York: New York Academy of Sciences. Annals of the New York Academy of Sciences. Vol. 1196.

New York State Climate Action Council. 2010. *Climate Action Plan: Interim Report*. Albany NY. November 9.

New York State Climate Office, 2003: "The Climate of New York: Snowfall." http://nysc.eas.cornell.edu/climate_of_ny.html.

New York State Department of Transportation (NYSDOT). https://www.nysdot.gov/

New York State Department of Transportation (NYSDOT). 2009. "Capital Program Proposal, New York State Department of Transportation, 2010-2015." October. https://www.nysdot.gov/programs/2010-2015-capital-program

New York State Sea Level Rise Task Force. 2010. *Report to the Legislature,* December 31.

New York State Thruway Authority, http://www.nysthruway.gov/

NPCC, *see* New York City Panel on Climate Change

NRC, *see* National Research Council

NYSCAC, *see* New York State Climate Action Council

Port Authority of New York and New Jersey. http://www.panynj.gov/port/.

Ramanathan, V., and Andrew M. Vogelman. 1997. "Greenhouse Effect, Atmospheric Solar Absorption and the Earth's Radiation Budget: From the Arrhenius-Langley Era to the 1990s." *Ambio* 26: 38-46

Rosenzweig, Cynthia, Radley Horton, David C. Major, Vivien Gornitz and Klaus Jacob.2007. *Climate Component*. In Metropolitan Transportation Authority, *August 8, 2007 Storm Report.* September 20.

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn, eds. 2011. *Responding to Climate Change in New York State*: *The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York.

Savonis, M. J., Virginia R. Burkett, and Joanne R. Potter. 2008. *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I*. U.S. Climate Change Science Program. Synthesis and Assessment Product 4.7.

Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds. 2007. *Preparing for Climate Change: A Guidebook for Local, Regional and State Governments*. Oakland, CA. Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, King County, Washington in association with ICLEI. Oakland CA.

Sussman, Edna, and David C. Major, Lead Authors 2010. "Law and Regulation." In New York City Panel on Climate Change, in New York City Panel on Climate Change, *Climate Change Adaptation in New York City: Building a Risk Management Response*, Cynthia Rosenzweig and William Solecki, eds. New York: New York Academy of Sciences, Annals of the New York Academy of Sciences. Vol. 1196. Chapter 5.

Titus, Jim. "Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?" 2002. In United States Department of Transportation Center for Climate Change and Environmental Forecasting, 2002, *The Potential Impacts of Climate Change on Transportation*. Federal Research Partnership Workshop Summary and Discussion Papers.

Titus, Jim, K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler and S. Jeffress Williams. 2009. *Coastal Elevations and Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. U.S. Climate Change Science Program. Synthesis and Assessment Product 4.1.

Transportation Research Board, *see* National Research Council, Committee on Climate Change and U.S. Transportation.

Trenberth, K.E. et al. 2007. "Observations: Surface and Atmospheric Climate Change." In Intergovernmental Panel on Climate Change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge UK. Cambridge University Press. Chapter 3.

United Kingdom Highways Agency, Transport Scotland, Welsh Assembly Government and The Department for Regional Development Northern Ireland. 2006. Design Manual for Roads and Bridges, Surface and Sub-Surface Drainage Systems for Highways. Geotechnics and Drainage. Volume 4.

U.S. Army Corps of Engineers, Federal Emergency Management Agency, National Weather Service, NY/NJ/CT State Emergency Management. 1995. *Metro NY Hurricane Transportation Study, Interim Technical Data Report*. New York: FEMA, November.

U.S. Global Climate Change Research Program (USGCRP). 2009. *Global Climate Change Impacts in the United States*. Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, eds. Cambridge, UK. Cambridge University Press.

University Transportation Research Center (UTRC), Region 2. 2009. RFP: Mainstreaming Climate Change Adaptation Strategies into New York State Department of Transportation's Operations RFP Number: C-08-09, Date Issued: October 28, 2008 (Revised: February 10, 2009).

Yohe, G. and R. Leichenko. 2010. "Adopting a Risk-Based Approach." In New York City Panel on Climate Change. *Climate Change Adaptation in New York City: Building a Risk Management Response*. C. Rosenzweig and W. Solecki, eds. New York: New York Academy of Sciences. Annals of the New York Academy of Sciences, Volume 1196. Chapter 2.

Zimmerman, Rae and Craig Faris. 2010. "Infrastructure Impacts and Adaptation Challenges," in New York City Panel on Climate Change, *Climate Change Adaptation in New York City: Building a Risk Management Response,* C. Rosenzweig and W. Solecki, Eds. New York: New York Academy of Sciences. Annals of the New York Academy of Sciences, Vol. 1196. Chapter 4.

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AR4	Fourth Assessment Report (IPCC)
AWG	Advisory Working Group (Columbia University)
CC & EE	Climate Change and Energy Efficiency Initiative (NYSDOT)
CEQR	City Environmental Quality Review (New York City)
CRIS	Climate Risk Information Summary (NYSDOT/Columbia)
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GCM	Global Climate Model
IDF	Intensity-Duration-Frequency curve
IPCC	Intergovernmental Panel on Climate Change
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transportation Authority
NPCC	New York City Panel on Climate Change
NRC	National Research Council
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
NYS	New York State
NYSCAC	New York State Climate Action Council
NYSDEC	New York State Department of Environmental Conservation
NYSDOT	New York State Department of Transportation

NYSERDA	New York State Energy Research and Development Authority
PANYNJ	Port Authority of New York and New Jersey
PATH	Port Authority Trans Hudson Corporation
RFP	Request for Proposals
SEQRA	State Environmental Quality Review Act (New York State)
TWG	Technical Working Group (NYSDOT)
UNFCC	United Nations Framework Convention on Climate Change
USACE	United States Army Corps of Engineers
UTRC	University Transportation Research Center