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NYSERDA Environmental Research Program Plan

Research Area 2:

Climate Change Adaptation

Final Report
Version 2

October 2014
Revised March 2016

Report Number 16-11

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

NYSERDA Environmental Research Program Plan
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1 Environmental Program Planning

NYSERDA's Environmental Research Program conducts comprehensive planning efforts designed to guide policy-relevant research projects. Working groups of science and policy experts have met and identified critical gaps and research needs in New York State, dividing their focus on the areas representing the major issues related to energy-related environmental impacts. The plan's potential users will include NYSERDA; other New York State, regional, and national research funding organizations; the scientific community; and policymakers. Implementation of the plan's recommendations will help maximize the use of limited resources to serve the needs of New York State and others. More information about the Environmental Research Program is available at http://www.nyserda.ny.gov/All-Programs/Programs/Environmental-Research. More information about the research planning process is available at http://www.nyserda.ny.gov/Cleantech-and-Innovation/Environment/EMEP/Research-Planning.

1.1 Overview

Electricity generation is responsible for adverse environmental and economic impacts including: degradation of lakes, streams, forests, and buildings from acid deposition; elevated levels of mercury in fish and other wildlife; human morbidity and mortality from poor air quality related to ozone and particulate matter; climatic changes that impact health, ecosystems, and economy; and direct and indirect environmental effects from alternative energy development. Although emission reduction efforts have resulted in some improvements, these impacts continue to affect New York State's sensitive ecosystems and vulnerable populations. NYSERDA's Environmental Research Program monitors and assesses environmental conditions and fosters technological innovation, providing objective, science-based information to help address immediate and long-term energy-related environmental challenges across New York State. The program aims to increase the understanding and awareness of the environmental and public health impacts of energy choices and emerging energy options, and to provide a scientific, technical foundation for creating effective and equitable energy-related environmental policies and resource management practices.

1.2 A Work in Progress

This plan should be viewed as a work in progress. As research findings become available and policies are implemented, it will be necessary to continually revisit, revise, and reconsider priorities within this plan to ensure that it effectively addresses the current and future environmental issues of concern.

2 Climate Change Adaptation

Since its inception, the Climate Research and Analysis component of the Environmental Research Program has significantly increased the understanding and awareness of the environmental impacts of energy choices and emerging energy options. It will continue to provide a scientific foundation for formulating effective, equitable, energy-related environmental policies and resource management practices that can both reduce greenhouse gas emissions and guide strategies to prepare for a changing climate. The program will build upon the environmental research capabilities in New York State, and address critical climate change-related issues facing the State and the region, including the needs of environmental justice communities, and create opportunities for innovation. This program will support research studies, demonstrations, policy research and analyses, and outreach and education efforts related to the following questions:

- What are the most cost-effective greenhouse gas mitigation strategies for New York to pursue?
- What are the current and projected impacts of climate change to energy, transportation, telecommunications, water resources, coastal zones, ecosystems, agriculture, public health, and the built environment in New York State, and how can risks associated with climate change be cost-effectively managed and minimized? Additionally, what opportunities exist to take advantage of opportunities related to a changing climate?
- What are the key parameters that need to be monitored to establish baselines and assess climate change impacts in New York?

The research needs discussed under this component of the plan are grouped generally by sector. However, in reality, many of the topics touch on multiple sectors. To the extent possible, research should consider the implications, co-benefits, and unintended consequences to other sectors, as well as the implications for environmental justice communities.

3 Crosscutting

Research topics do not always pertain solely to one sector or another. Listed here are research needs that would benefit multiple sectors. Although outreach is not necessarily considered research, it is an important aspect of the research process, particularly in the context of climate change, and is therefore included here.

3.1 Outreach

3.1.1 Research Focus

- Raise the awareness of various audiences about the changes in natural processes and weather events to be expected from climate change, as well as the public health significance and related costs of climate change.
- Help incorporate climate science into education curricula to bring the most current, science-based information to tomorrow's leaders.
- Target outreach to communities affected by climate-related events--those that have occurred in the past, as well as those projected for the future. There is a particular need to reach emergency managers in these communities, to enable them to be better prepared for climate-related emergencies. Outreach should also be targeted to particularly vulnerable populations.

3.2 Projections

3.2.1 Research Focus

Update and refine climate projections periodically, to ensure that decisions are being made with the best available science. Projections of changes in wind, humidity, and soil moisture content have not generally been included in previous work, but would be useful to have. Uncertainties in projections need to be reduced (e.g., in extreme events).

Downscaling humidity projections is important for determining future apparent temperatures, which can be critical to the electricity and public health sectors. There is some question about whether this type of information can be provided in a way that will be useful, given the uncertainties involved. A first step would be to conduct an analysis reviewing the current state of the science on this issue.

Improve information on the distribution of coastal storm impacts over the landscape (historic and future) by combining information on the frequency and intensity of potential severe storm impacts (e.g., erosion, surge, river and stream flooding, velocity water flows, extreme winds). A better understanding of where storms will have impact, how frequently, and the nature of the impacts will help guide decisions in adapting to reduce future damages from these storms in the future.

3.2.2 Relevance to Other Research in the Region and the Nation

- Research in this area should be coordinated with the NYS RISE initiative (NYS Resiliency Institute for Storms and Emergencies) to the extent possible (www.nysrise.org).

3.3 Other Crosscutting Research

3.3.1 Research Focus

- Develop and pilot an adaptation planning roadmap/process for communities, and identify tools and data that would assist with the process. A number of approaches currently exist, which could be tailored to New York State communities and could vary slightly for different regions of the state (e.g., coastal areas versus Adirondacks). Wherever possible, the approaches should integrate with existing NYS Department of State planning processes and the hazard assessments required by the New York State Office of Emergency Management. A related need is the development of a New York State-specific pre-event long-term recovery planning process, similar to that developed by the American Planning Association (https://www.planning.org/pas/reports/pdf/PAS_576.pdf).
- Develop guidance for local governments on how to access funding to restore streams after flooding events, as well as other types of projects (e.g, living shorelines/alternative shoreline stabilization methods, green infrastructure). Local communities often have a difficult time finding funding opportunities; there is a need to match communities, rehabilitation projects, and other ecosystem restoration efforts with available funding sources for which they would qualify.
- Develop a statewide, standardized reporting system for climate-related impacts. There is currently a standardized reporting process in effect after disaster declaration in order to qualify for hazard mitigation funding, and the NYS Department of State has developed a draft system for storm impacts. Rather than requiring additional, new reporting by communities, a system should integrate climate-related impacts into existing processes where possible. Ideally, such a system would incorporate the data needs required for all types of funding sources and would allow communities to demonstrate that requested funding would be helping to achieve a more resilient outcome in the future.

- Collect LiDAR for the inland regions of New York State. Although this has been done for much of coastal New York, including the Great Lakes, inland regions are still lacking this information. Detailed topographical information would greatly improve floodplain mapping for these inland areas, some of which have never even had Federal Emergency Management Agency (FEMA) flood maps drawn. Areas of prioritization should be based on population, flood risk, and existence/age of current floodplain mapping. Existing and in-progress LiDAR acquisitions are available on the NYS GIS Clearinghouse site (http://gis.ny.gov/elevation/lidar-coverage.htm). Any proposed projects should be coordinated with these and other efforts (e.g., USGS).
- Perform economic analyses of climate change impacts and the relative value of various adaptation strategies. Cost of adaptation is often a large factor in implementation, so such analyses are needed in all sectors to help guide adaptation decisions. Include life-cycle costs, nonmonetary costs/benefits, failure rates and consequences, and whether redundant measures are needed. For the coast or water resources, such analyses should consider the most recent Council on Environmental Policy's *Principles and Requirements* criteria for federal agencies (http://www.whitehouse.gov/administration/eop/ceq/initiatives/PandG).
- Continue research to analyze the urban heat island effect in New York City and other major cities in New York State, as well as on strategies to reduce the effect. As extreme heat is projected to increase in the future, the urban heat island effect will increase in importance. The public health and energy co-benefits of reducing UHI should also be considered.
- Review design guidelines, specifications, and standards for new and updated critical infrastructure and identify where the standards could be updated to better incorporate climate change and increase resiliency of new and existing infrastructure.
- Develop a framework for describing, monitoring, assessing, and reporting progress on adaptation efforts within the State. Such a system would allow those considering implementing adaptation strategies to see what has already been done and worked for other communities throughout the State. One aspect of this could be a system for providing information on what NYS and local agencies are doing within their own organizations with respect to climate adaptation. The Climate Smart Communities certification tracking system through the NYS Department of Environmental Conservation (DEC) could serve as the basis for such a system.
- Analyze the economic and environmental justice impacts of climate change adaptation policies on different populations, areas, and industries throughout the State. Traditionally underserved populations need to be considered when implementing adaptation strategies.
- Conduct an analysis of interdependencies across State boundaries and the resulting effects on climate change impacts. Such an analysis could include invasive species, energy systems, regional health concerns, economic exchange, and others.
- Quantify the impacts of climate change on the lifespan of specific types of infrastructure and facilities (e.g., power dams, wastewater plants, culverts, bridges). There is also a need to look at the environmental impacts of infrastructure failure, as well as how the development of new infrastructure would impact the balance of natural systems. Some work is ongoing in this area, so it could be possible to extend the knowledge from existing studies to similar infrastructure types (e.g., NYS Department of Transportation's tristate infrastructure vulnerability assessment, Federal Highway Administration [FHWA] study).

- Similarly, develop a process to help managers assess how climate change will affect asset-management investment cycles and life cycles of major investments, acknowledging that future assets/processes may be different under future climate. Is existing infrastructure more or less vulnerable? Will designing new infrastructure have a better cost-benefit ratio? As we design new infrastructure, are there things we can do to make them more cost- effective? It would be helpful to provide some general-level information to alleviate some of the cost for site-specific studies.
- Develop a database of adaptation options and design guidelines for specific types of infrastructure and facilities, to allow planners easy access to multiple options to consider. As an example, DEC uses a database of options to manage storm water. Such a database should be created for all sectors in the State. Any such database should be coordinated with the NYS Climate Change Science Clearinghouse, which is currently under development.

3.3.2 Relevance to Other Research in the Region and the Nation

- Cornell University's Water Resources Institute has some ongoing research in the area of climate and asset management, including net-zero energy, resource recovery, combined heat and power (CHP), and digesters, which could be considered or built upon (http://wri.eas.cornell.edu/). Also consider ongoing work by the NY RISE initiative on identification of vulnerabilities of critical facilities and flooding impacts on infrastructure (www.nysrise.org).
- The Mid-Atlantic Research Council on the Ocean (MARCO) may be doing some work in the area of cross-state interdependencies (http://midatlanticocean.org/).
- The Environmental Finance Center at the University of Maryland recently released a Local Government Stormwater Financing Manual. Although this manual does not identify funding sources for specific communities, it presents a framework for sound fiscal planning and identifies important financing issues and opportunities. It includes a dedicated section on green infrastructure practices (http://efc.umd.edu/localgovernmentstormwaterfinancingmanual.html).

4 Agriculture

Climate change may bring new opportunities to New York's agricultural sector but will also pose new risks and challenges for farmers and land managers. Further research is needed to better understand how warmer weather and changes in the water cycle, as well as extreme weather events or violent storms, will likely affect agricultural yields of crops and dairy farms, or provide new opportunities for controlled environment agriculture. In the short term, higher carbon dioxide (CO_2) levels and warmer temperatures may increase the yield of some crops, such as grape crops in the Hudson Valley, or extend the season of others, such as specialty crops. However, because higher temperatures may favor invasive species at the expense of indigenous species that cannot adapt to changes in climatic conditions, or may allow novel disease and pest organisms into the New York ecosystem, increased pesticide and herbicide use and loss of biodiversity are expected, while short-term droughts are likely to increase the need for artificial irrigation and improved soil health in the region and increase stressors on farm animals. The agricultural sector also has the potential to help reduce greenhouse gas emissions as well as mitigate emissions from other sources, and the potential strategies remain to be identified and/or better characterized.

4.1 Research Focus

- Develop new decision tools that integrate economic, environmental, and environmental-justice impacts of agricultural adaptation options, to assist farmers and policymakers in making decisions for the future climate. Benefit-cost analyses and tools comparing different methods of optimizing feed rations (e.g., to reduce the effects of heat stress, reduce enteric methane production), varying fertilizer needs for different crops, and planning for drought, orchard turnover, manure storage, etc. would be of particular importance. Incorporating greenhouse gas mitigation into such efforts would also be valuable.
- Evaluate the capacity of existing agriculture and forestry programs for identifying and monitoring invasive species, which will likely become more problematic as climate change continues into the future. This issue is also important in the context of ecosystems and public health.
- Develop adaptation strategies to minimize the negative effects of climate change on New York State's high-value perennial crops (e.g., apples, grapes). Strategies could include the development of more hardy varieties, identification of crops that will fare better under New York's future climate, better frost protection systems, pruning and mulching strategies, and the use of tools such as heaters, wind machines, or overhead sprinklers to protect crops from frost.
- Develop better weather prediction tools and advanced warning systems to provide farmers with more lead time to prepare for adverse weather conditions, which could increase under future climate.

- Evaluate the effectiveness of soil carbon sequestration as a mitigation measure. That is, determine whether soil carbon sequestration is a practice that affords real and measureable mitigation results over the long term, or are mitigation benefits lost when previously untilled soils are eventually tilled.
- Develop strategies to influence a change in management styles. Identify what can be done to increase the likelihood that farmers will adopt the practices necessary to adapt to a changing climate.
- Explore opportunities related to controlled environment agriculture practices that may assist the agricultural sector adapt to, or take advantage of our changing climate in New York State.

4.2 Relevance to Other Research in the Region and the Nation

Any projects in this sector would benefit from coordination with:

- Cornell Institute for Climate Change and Agriculture (http://climateinstitute.cals.cornell.edu).
- Cornell Cooperative Extension (http://sp.cce.cornell.edu/EnergyClimateChange/Pages/default.aspx).
- NYS Invasive Species Council (www.dec.ny.gov/animals/6989.html).
- New York Farm Viability Institute (www.nyfvi.org).
- NYS Soil and Water Conservation Committee (www.nys-soilandwater.org).

5 Coastal

High water levels, strong winds, and heavy precipitation resulting from severe coastal storms already cause billions of dollars in damages and disrupt transportation and power distribution systems. Sea level rise will greatly amplify risks to coastal populations and will lead to permanent inundation of low-lying areas, more frequent flooding by storm surges, and increased beach erosion. Barrier islands are being dramatically altered by strong coastal storms as ocean waters overwash dunes, create new inlets, and erode beaches. Loss of coastal wetlands from sea level rise will reduce species diversity, including fish and shellfish populations upon which the fishing industry relies, and will also reduce natural protection from storms and erosion. Saltwater could reach farther up the Hudson River and into estuaries, as well as into groundwater in coastal areas, contaminating drinking water supplies.

5.1 Tidal Wetland Trends

5.1.1 Research Focus

- Update regulatory maps of tidal wetlands in New York State. These maps are critical for conducting trends analysis on wetlands. In some coastal areas, they have not been updated since the 1970s. Many changes have taken place since then, including habitat loss due to sea level rise, unexplained loss of saltmarsh, and other factors. On Long Island, status, trends, and projections analyses for tidal wetlands are needed. Determining how much has been lost to sea level rise and land-use issues will help determine how and where to conserve, enhance, or create new tidal wetlands. Prioritization of areas might include locations with highest rates of development. Based on these maps, improve understanding of the factors contributing to wetland loss in New York City (NYC) and on Long Island through targeted research and wetland trends analysis.
- Investigate the value of carbon sequestration or “blue carbon” in tidal wetlands in New York State; how sequestration differs in historic, restored, and constructed wetlands; and how the sequestration potential changes and/or may change over time with climate change. There is also a need to clarify other roles and benefits of wetlands, such as filtration of storm water runoff and the ability to decrease storm surges.
- Investigate how changes in Mean High Water due to sea level rise will affect public trust lands, natural and nature-based features that provide risk reduction and resiliency, and private/public ownership. This would be relevant to tidal wetland and submerged aquatic vegetation (SAV) conservation, and build on Sea Level Affecting Marshes Model (SLAMM) results and other land ownership/habitat migration analyses with bathtub SLR projections.
- Refine the Sea Level Affecting Marshes Model (SLAMM) results for freshwater tidal environments in the Hudson Rivers Estuary.

- Provide a better understanding of tidal marsh surface dynamics to inform tidal wetlands management, and to identify early signs of marsh deterioration. Concern exists among marsh managers that in at least one Hudson River tidal marsh (Piermont Marsh) a progressive increase in ponded areas is contributing to loss of marsh vegetation and possibly marsh integrity, due to unknown factors (possibly including sea level rise, Phragmites expansion and associated increased sediment accretion, muskrat population increases, storm surge-related ponding, and compaction).

5.1.2 Relevance to Other Research in the Region and the Nation

- The Nature Conservancy, DEC, HRNERR, and NYC should be consulted on these types of projects, as these organizations and programs have related, ongoing work. Hudson River tidal wetlands (Hastings-on-Hudson to Troy) were mapped in 2007. HRNERR acquired a set of aerial photos for 2014 from Hastings-on-Hudson to Troy. These are currently being interpreted for submerged aquatic vegetation (SAV) only, with a 2014 SAV Map scheduled to be finalized in 2016. There is currently no plan to interpret the 2014 aerial photos for tidal wetlands. Another aerial photo acquisition is planned for 2016.
- NYC has done some work on updating wetland maps, but there are still needs in the Hudson Valley, Long Island, and other regions of the State.
- NYSDEC and EPA, with assistance from NEIWPCC and TNC, completed a tidal wetland trends analysis comparing 1974 wetlands with 2006/2008 wetlands.

5.2 Natural or Nature-Based versus Traditionally Engineered Shorelines

5.2.1 Research Focus

- Develop a consistent monitoring and evaluation framework to track the costs, resiliency performance, and ecological effects of natural, engineered, and hybrid coastal infrastructure over time, to inform design, construction, placement, and regulatory decision making. The framework should include both pre- and post-construction monitoring goals and should consider the priorities of including life-cycle costs, failure rates and consequences, and nonmonetary costs/benefits. Understanding the resiliency of these different options will allow for better decision making regarding adaptation options. There is a need for monitoring of existing structures, as well as gathering baseline, pre-construction data where large-scale projects are being planned.

- Support research and demonstrations of nature-based or ecologically enhanced engineered shorelines. There is much discussion in the literature about the effectiveness of nature-based shorelines, but few details or demonstrations of these benefits in New York State. There is a need for a detailed assessment of the effectiveness of various protective measures that would help determine the negative or positive impacts of a range of shoreline treatments on coastal and nearshore ecosystems, as well as on water quality. Guidance and tools to allow for cost/benefit analysis of structural versus nonstructural shore protection solutions would be beneficial, particularly those that consider ecosystem services and maintenance of natural processes. Benefit-cost analysis should include life-cycle costs, failure rates and consequences, and nonmonetary costs/benefits, as well as comparison to structural solutions. Given that there are now a few installations of nature-based shorelines in New York State, it may now be possible to conduct a comparison of performance versus structural solutions. Related to this research would be an assessment of how offshore sand waves mitigate or increase the impacts of coastal inundation and erosion. Also related would be understanding the tradeoffs associated with different marsh management strategies, in terms of community protection and native biodiversity protection (e.g., the role of marsh in storm surge and flood protection at Piermont Marsh), or of different wetland restoration and management practices in light of sea level rise (e.g., on Long Island).
- Complete a geomorphological classification of the New York State shoreline. Understanding shoreline stress capacity is helpful in identifying suitable management options as sea levels rise. NYC produced a guidance document on shoreline conditions and management options to reduce storm impacts, which analyzed length of fetch/waves, geological substrate, armoring, nearshore slope, and other factors (e.g., habitat value or connectivity of important habitats). (http://www.nyc.gov/html/sirr/downloads/pdf/final_report/Ch3_Coastal_FINAL_singles.pdf). The document has proven valuable for policymakers and planners, and it would be valuable to have for the rest of the state, including the Great Lakes and Finger Lakes. Other factors could also be incorporated as well, such as sediment availability and upland vegetation. Having a consistent, statewide classification of the shoreline would be useful and applicable to coastal management efforts, whether it be using the NYC methodology or improving upon it.
- Complete a shoreline structures inventory for the New York State coastal shoreline to develop a better sense of the condition of existing shoreline structures. The information collected on shoreline structures could include feature design/material/expected working life, construction and maintenance history, and failure record. This type of work has been done for the Hudson Valley and parts of Lake Ontario, but not for Long Island. This inventory could be used to identify parcels best suited for specific adaptation strategies, such as buy-out and relocation.
- Investigate the use of "blue carbon" in tidal wetlands in New York State with respect to carbon sequestration. Recent research has proposed that wetlands have the ability to store more carbon than terrestrial forests; current literature discusses both the importance of carbon sequestration in coastal wetlands and the importance of avoiding wetland conversion (and the subsequent release of stored carbon). There is a need to better understand how the functionality of wetlands will change as water levels rise, particularly as it relates to their ability to sequester carbon, including the function of restored versus natural versus newly constructed wetlands. There is also a need to clarify other roles and benefits of wetlands, such as filtration of storm water runoff and the ability to decrease storm surges.

5.2.2 Relevance to Other Research in the Region and the Nation

- Cost/benefit analysis work should draw upon work being done by the U.S. Army Corps of Engineers (USACE) national assessment. Work should also consider the most recent Council on Environmental Policy's *Principles and Requirements* criteria for federal agencies (http://www.whitehouse.gov/administration/eop/ceq/initiatives/PandG)
- The DEC has developed a pilot research plan for natural or nature-based coastal infrastructure for Howard Beach and is developing a research plan for the use of natural or nature-based coastal infrastructure in NYC. DEC is also developing a guidance document for natural or nature-based shorelines with regard to tidal wetland regulations and permitting.
- Work on offshore sand waves should build on and integrate with similar work by the U.S. Geological Survey (USGS).
- HRNERR and the Stevens Institute, through the Sustainable Shorelines program, are in the process of conducting a forensic analysis on six shoreline sites—three with traditional engineered protection and three with ecologically enhanced or nature-based treatments. They have also completed research on how different design components can affect habitat use and diversity of aquatic species and are assessing performance during Hurricane Irene, Tropical Storm Lee, and Superstorm Sandy. Research on effectiveness and resiliency of shoreline treatments should build upon this work (http://www.hrnerr.org/hudson-river-sustainable-shorelines/).
- The U.S. Department of the Interior issued a number of grants to New York and neighboring states in 2014 that could be relevant to this and other coastal work (https://www.doi.gov/sites/doi.gov/files/migrated/news/upload/2014-grants-list-v2.pdf).
- NOAA/USACE SAGE is a national effort to establish a community of practice related to "Living Shorelines." Their website contains a map and database of projects in the mid-Atlantic, which is planned to expand nationwide. (www.sagecoast.org)

5.3 Other

5.3.1 Research Focus

- Assess the effects of sea level rise on the salt front and salinity levels in New York State estuaries, which could affect drinking water supplies in coastal areas. For example, salinity changes in Long Island Sound could affect aquifers on the North Shore; communities drawing from the Hudson River could have their water supply affected by changes in the salt front in the river, as could desalination plants along the river. There has not been much modeling of this as of yet. Some work has been done on Long Island, but more work is needed; very little research has been done in the Hudson. Research could consider the counteracting effects of increased freshwater run-off on the new salinity regime.
- Assess the effects of ocean acidification and warming ocean waters on near-shore and coastal resources (e.g., shellfish, crustaceans, finfish, sea turtles and marine mammal distributions). Work could also include research on potential adaptation options for these impacts.

- Assess the impacts of dredged material disposal including climate change related effects. The disposing of dredged material in Long Island Sound and in Lakes Ontario and Erie, must first meet the Clean Water Act or Ocean Dumping Act (projects greater than 25,000 cubic yards in Long Island Sound) water quality standards. These standards apply to discrete event disposals and provide little to no insight regarding cumulative effects, bioaccumulation, or leaching attributable to a changing climate (ocean acidification, warming waters, etc.). A reliable model should be developed to identify potential effects, track actual effects, and understand the long-term impacts of open water disposal of dredged material containing chemical compounds. Work should include dredged material reaction to changes in acidification and warming temperatures in adverse ways that are not currently understood or documented in the Clean Water Act or Ocean Dumping Act standards. The research would fill a critical data gap for understanding the long-term impacts of disposing dredged material in open, dynamic and changing water environments.
- Map the location and status of critical features and communities (natural and human-made) in high-risk coastal areas, which will aid in prioritizing vulnerability assessments and implementation of adaptation strategies. Many communities in the New York Rising Community Reconstruction (NYRCR) program have already identified and mapped these facilities, but other coastal communities not included in the NYRCR program would greatly benefit from identifying critical facilities and features of high community value.
- Perform ecosystem service valuation of protective coastal habitats for the New York coast (e.g., using the InVEST Coastal Protection Toolbox). Develop a practical methodology for State project prioritization and approval reviews to help inform benefit-cost analyses and inform decision makers on the benefits of these coastal habitats. The Nature Conservancy and others have applied the InVEST tool to Long Island in their Coastal Resilience online mapping tool; it would be useful to have detailed results for other New York State regions. This work could also be applied as a pilot study of sample sites in New York State to explore ecosystem service types and values.

6 Ecosystems

Over the next several decades, New York State is likely to see widespread shifts in species composition in forests, waterways, and other natural landscapes across the State. Climate change will favor the expansion of some invasive species (such as kudzu and the hemlock wooly adelgid) and diseases into New York State, while some habitat and food generalists (such as white-tailed deer) may also benefit. A longer growing season and the potential fertilization effect of increasing carbon dioxide could increase the productivity of some hardwood tree species, provided growth is not limited by other factors such as drought or nutrient deficiency; however, carbon dioxide fertilization tends to preferentially increase the growth rate of fast-growing species, which are often weeds and some invasives. Lakes, streams, inland wetlands, and associated aquatic species will be highly vulnerable to changes in the timing, supply, and intensity of rainfall and snowmelt, groundwater recharge, and duration of ice cover. Increasing water temperatures will negatively affect brook trout and other native coldwater fish.

6.1 Monitoring

6.1.1 Research Focus

- Develop reliable indicators, monitoring strategies and methods, and data-collection standards for climate change impacts on biodiversity and ecosystem functions, to improve the quality of monitoring data. A coordinated approach would improve the quality of monitoring data and increase its usefulness for informed risk analysis, asset management, and resource-management decisions. Specific examples include a statewide system similar to the Sentinel Monitoring program of the Long Island Sound Study (http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/), or a systematic way to record high-water marks after storms and floods.
- Develop a long-term monitoring program for the coastal areas of New York State, to gather baseline ecological data, including benthic habitat surveys, to inform regulatory decisions, track ecosystem resilience, and evaluate large-scale implementation of resiliency measures over time. Continue to support established long-term monitoring programs.
- Improve understanding of the ecosystem interactions of climate change and other stressors (e.g., land-use change, pollutants). For example, how does alteration of the carbon cycle interact with other pollutants and nutrients? Studies could include the effects of leaf-out changes on mobilization of mercury, or developing new efficient methods to monitor, quantify, and understand the impacts of climate change and elevated carbon dioxide on ecosystem productivity and water, nutrient, and energy cycling.

- Identify stressors that could feasibly be managed, reduced, and/or eliminated and which would have the most potential to ease pressure on ecosystems if removed. Such information could help define management practices and assist in prioritizing and targeting stressors. Focusing on the most vulnerable habitats could be assisted by the National Wildlife Federation assessment on habitat vulnerability (http://www.nwf.org/~/media/content/specialty%20programs/Climate-smart-conservation/Adaptation-Reports/Assessing_the_Vulnerability_of_Key_Habitats_of_NY.pdf) and The Nature Conservancy spatial mapping projects.
- Track changes in soils over time, with a particular emphasis on organic matter. Soil organic matter is a major store of carbon dioxide generated by energy use, and reflects a suite of different climate-sensitive processes that include temperature, available moisture, and vegetation. Soils also store many pollutants that result from energy use such as sulfur, mercury, and nitrogen. Better data on soils are needed in regions such as the Adirondack Park to track the response to climate change and to more fully understand the long-term environmental behavior of other pollutants. Wetland soils in particular are of interest and concern because of the critical role wetlands play in support of biodiversity and their ability to sequester carbon and affect mercury cycling. Agricultural soils are also of interest, with respect to carbon losses and soil carbon storage. As we incorporate more green infrastructure that will percolate rainwater into local aquifers, information on organics and contaminants in soil, or changes in soil due to this increased infiltration, will be of value.
- Track changes in availability of water resources over time and model the effects of altered hydrology, from both human and ecosystem use perspective. Changes in flow regimes will alter transport/retention and habitat suitability, and could lead to changes in lake stratification and potential dissolved oxygen problems as waters warm. A better understanding of how these changes are occurring in response to climate change will aid adaptation decision making.
- Reduce uncertainties in ecosystem and species responses to projected climate change in order to increase adaptive management options. For example, document and project changes in plant community composition with climate change, and improve understanding of present and future thermal stress on aquatic cold-water species. The magnitude and details of extinction threats are uncertain, which presents a challenge to planning and implementation of long-term conservation strategies.
- Use environmental genomics (e.g., eDNA) to improve information on ecosystem diversity and health. This approach looks at changes in the DNA structure of flora and fauna and examines the relationship between these changes and climate change, which can help identify the impacts from climate change. It is also possible to identify the presence or absence of species in an ecosystem by using DNA to examine impacts on a larger scale, including use as early warning for invasive species. The USGS has used this approach to determine how aquatic communities are being affected by changes in the climate.

6.1.2 Relevance to Other Research in the Region and the Nation

- Consideration of existing efforts will be key. New monitoring efforts should be integrated with the NYS Climate Change Science Clearinghouse wherever possible.
- The Hudson River Estuary Program is performing some monitoring work regarding impacts to biodiversity in the Hudson Valley in their biodiversity monitoring program for amphibians, as well as fish population monitoring in the Hudson River (http://www.dec.ny.gov/lands/5094.html).
- The Cary Institute of Ecosystem Studies is doing some work on ecosystem interactions of climate change and other stressors, particularly on elevated carbon dioxide (www.caryinstitute.org).
- The NYS RISE initiative has several relevant projects planned or under way. One project plans to integrate multiple monitoring systems targeting coastal zones, with an expected outcome of observable climate change trends for coastal ecosystems. A second project is investigating the impacts of storms on coastal ecosystems and fisheries. Any monitoring projects should be mindful of these efforts for future incorporation into their proposed website of synthesized monitoring data (www.nysrise.org).
- The NYC Department of Environmental Protection has done some work on climate and land-use change in their watershed, which could be used as a model or starting point.
- DEC's New York Ocean Action Plan (OAP) contains objectives and actions to improve understanding of current trends and projected changes expected within the New York Bight, including potential impacts and ocean-related vulnerabilities associated with human activities and climate change. In addition to establishing ecological and socioeconomic benchmarks through baseline and ongoing long-term monitoring efforts, DEC will also be engaging in the development of a suite of ocean indicators, including the various ecosystem services, as a metric of ecosystem health (http://www.dec.ny.gov/lands/84428.html).
- The Long Island Sound Study has developed and continues to work on a climate change monitoring network (sentinel monitoring—http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/) and associated data citation clearinghouse.

6.2 Corridors

6.2.1 Research Focus

- Develop guidelines and best practices for management of riparian corridors, buffers, and floodplains to achieve joint goals of water quality protection, wildlife dispersal corridors, flood management, public safety, and other riparian protection co-benefits. Mapping of riparian corridors may be needed and could include recommendations for a corridor zoning approach with distinct uses within delineated riparian corridor zones. This type of research could provide the scientific foundation to support policy decisions.

- Conduct research on connectivity and the needs of both terrestrial and aquatic species, given climate-change-driven temperature and precipitation changes, as well as indirect effects on the distribution of vegetation in perennial streams. This work would help identify which species would benefit most from better aquatic and terrestrial connections, as well as which could be at risk from increased connectivity with exotic/invasive species.
- Conduct research on the geographic distribution of storm flood extents for the Great Lakes and inland water bodies, to help communities understand the likelihood of flooding in their area. In particular, a methodology for identifying the relevant factors contributing to flooding on specific water bodies or watersheds (debris blockages, ice jams, impervious surface runoff, extreme precipitation in the watershed, storm water collection system flows, spillway overflows, channel migration, etc.) and predicting flooding, and delineation of the 10-year floodplain would be particularly useful. This information is generally not included on FEMA floodplain maps. Potential priority site locations include the Great Lakes, the State Canal System, Lake Champlain and the Finger Lakes, and inland water bodies listed in Executive Law Article 42 Section 911 (http://www.dos.ny.gov/opd/programs/pdfs/Article_42.pdf). Priority site locations would include urban riverine communities with known flooding issues and that have high levels of development, infrastructure, or vulnerable populations at risk.
- Measure patterns of dispersal behavior to allow better corridor design and to improve understanding of how strategic corridors can impact habitat and species' health (e.g., by decreasing habitat fragmentation, preserving/enhancing biodiversity, preserving/enhancing genetic variability).

6.2.2 Relevance to Other Research in the Region and the Nation

- Research should consider existing projects, such as NYSERDA's corridor mapping projects and the NY Natural Heritage Program's maps and databases (http://www.dec.ny.gov/animals/29338.html).
- Connecticut River landscape conservation design is a NALCC initiative that may be expanded for the east coast. (www.NorthatlanticLCC.org). The initiative is piloting tools and strategies for conserving connected networks of lands and waters in the face of climate change and other stressors. The organization provides tools in a comprehensive way for NE coast managers to use in planning and assessment.

6.3 Invasive Species

6.3.1 Research Focus

- Identify which invasive species pose the greatest threats to the State's ecosystems and develop a rapid response plan to aid the State in preparing for future invasions by non-native species. A focus should be on identifying which species are causing, or could cause, the most harm, as well as determining which species are most likely to reach New York State. Identify routes of invasion and potential methods of regulating or blocking the invasive species. Some spread of species from other regions may be needed to fill the space of natives that will no longer be viable under future climates. This recommendation from the NYS Invasive Species Task Force has not yet been accomplished (http://www.dec.ny.gov/animals/6989.html). There is also a need for consideration of integrated pest management as an adaptation tool.
- Develop benefit-cost analyses for the control of invasive species versus no control. Such an analysis could be helpful in supporting a defensive movement against invasive species, if the economic impact of their presence is measured. Consider the cost of prevention, early detection/eradication, and no intervention.

6.3.2 Relevance to Other Research in the Region and the Nation

- PRISM groups may be working on rapid response plans for some species in some areas (http://www.nyis.info/?action=prism_main).
- DEC's New York Ocean Action Plan (OAP) contains a discussion of invasive species that is relevant to this research (http://www.dec.ny.gov/lands/84428.html).

6.4 Adaptation Strategies

6.4.1 Research Focus

- Design management interventions to reduce the vulnerability of high-priority species and communities, and determine the minimum area needed to maintain boreal and other threatened ecosystems.
- Develop silvicultural methods to encourage desirable species likely to be favored by climate change while discouraging invasive and otherwise undesirable species.
- Identify conservation strategies and measures of effectiveness to inform adaptive management (e.g., metrics of resiliency and ecological benefit of an implemented project). Having metrics to measure the effectiveness of these strategies will help support agency and local decision making.
- Continue mapping and developing conservation plans for coastal submerged aquatic vegetation populations and other shallow-water species in marine areas, and analyze trends to identify areas of loss and gain. These populations are very important to coastal ecosystems but are vulnerable to climate change, specifically sea level rise. This work is being done in the Hudson River, but the need still exists for marine regions of the State. This work could encompass fauna in these areas as well.

- Develop strategies for restoration, management, or protection of critical habitats (e.g., tidal wetlands) damaged by storms or compromised by development, to ensure continued habitat services, coastal protection, and storm water filtration for sediment, nutrient, and water quality management, keeping future climate in mind. There could be an evaluation of the contribution of natural sediment transport and transition processes to the maintenance of habitat types. There is a need for regional consistency with this work. Are New York and neighboring states approaching restoration in the same way? Such consistency would help protect against the impetus to restore something quickly and potentially incorrectly, if there are established approaches in other states and agencies to which we can refer. Additionally, strategies implemented in one region may have potential co-benefits, or unintended consequences in an adjacent region if a coordinated approach is not taken.
- Quantify ecosystem services including function and monetary value for use in cost/benefit analyses of policies, programs, and projects, and to inform changes to regulations. Develop a framework by which counties and local governments or other partners can estimate the value of ecosystem services and the potential value of proposed environmental restorations.
- Pilot-test adaptation and management options to develop strategies that better balance economic, environmental, and social welfare costs and benefits. Determine a programmatic approach for considering and incorporating positive and negative externalities into cost/risk analyses and management decisions. Pilot-test the approach on sample adaptive measures and determine economic, social welfare, and environmental outcomes.
- Identify beneficial uses of dredged material. The Long Island Sound region is on a predicted pathway to dredge approximately 50 million cubic yards of material from NY and CT rivers over the next 30 years. This material, when found to be compatible with wetland soils, could be beneficially used to restore eroded wetlands to protect against the energies associated with storm surge and increased erosion rates from rising sea levels. The research would provide much needed information of how and where to place the compatible dredged materials, the costs associated with wetland restoration, the cost savings achieved from increased protection for the local and regional communities from the storm protection (a cost-benefit analysis of beneficial use versus open water disposal), and costs of removing material from the littoral transport system. This research would identify and fill data gaps in understanding how to most effectively use the dredged material for long-term restoration and storm protection.
- Pilot test alternative project evaluation tools for more comprehensive reporting on cost, environmental effects, and social welfare effects. The objective would be to replace benefit/cost analysis with accounting systems that better reflect overall outcomes. This point relates to the previous bullet for better cost/benefit approaches for climate change adaptation.

6.4.2 Relevance to Other Research in the Region and the Nation

- This research could be informed by the habitat and species-based vulnerability assessments performed by DEC, as well as by the NYSERDA-funded spatial mapping projects with The Nature Conservancy.
- The Jamaica Bay restoration projects include consideration of sea level rise and may have results relevant to this type of research (http://www.nps.gov/gate/naturescience/marshrestoration.htm).

- The U.S. Department of the Interior issued a number of grants to New York and neighboring states in 2014 that could be relevant to this work. (https://www.doi.gov/sites/doi.gov/files/migrated/news/upload/2014-grants-list-v2.pdf).
- The Long Island Smart Growth Resiliency Partnership is funding a public/private Long Island Ecosystem Services Assessment team to value (quantitatively and qualitatively) two ecosystems/watersheds on Long Island. The analysis and methodology will contribute to the ongoing implementation of the NYS Community Risk & Resiliency Act, as well as other relevant federal, state and local activities. The Partnership is also planning a research symposium on this subject for 2016.

7 Energy/Telecommunications

Climate change is impacting both energy demand and supply. Climate change will adversely affect system operations, increase the difficulty of ensuring adequate supply during peak demand periods, and worsen problematic conditions, such as the urban heat island effect. More frequent heat waves will cause an increase in the use of air conditioning, stressing power supplies and increasing peak demand loads. Increased air and water temperatures will decrease the efficiency of power plants, as they decrease cooling capacity. Coastal infrastructure is vulnerable to flooding as a result of sea level rise and coastal storms. Hydropower is vulnerable to projected increases in summer drought. Transformers and distribution lines for both electric and gas supply are vulnerable to extreme weather events, such as heat waves and flooding. Higher winter temperatures are expected to decrease winter heating demand, which will primarily affect natural gas markets, while increases in cooling demand will affect electricity markets.

Telecommunication infrastructure is vulnerable to heavy precipitation events, flooding, hurricanes, and other extreme weather events, which are projected to change in frequency and/or intensity. The delivery of telecommunication services is sensitive to power outages, such as those resulting from the increased demand associated with heat waves, which are expected to increase with climate change. In coastal and near-coastal areas, sea level rise in combination with coastal storm surge flooding will be a considerable threat.

7.1 Research Focus

- Develop approaches for optimizing coordination and communication among all parties with responsibilities during an emergency event. As severe weather events are likely to increase under climate change, emergency conditions may increase as well. There is a need for communities to be better prepared for such events. Several ongoing projects are geared toward improving coordination during emergencies, but these efforts are not well coordinated.
- Develop models, guidance, standards, and financial support where possible to help local governments implement adaptive measures for priority communication infrastructure where they have jurisdiction.
- Develop and expand alternative communication technologies to increase redundancy and/or reliability, which would allow communication systems to remain operable during emergency events. Exploration of the potential to connect these systems to community power or distributed generation would be beneficial, as well as gaining a better understanding of the relative energy-efficiency of these new technologies.

- Conduct an assessment of the co-dependency between the communications and power sectors and their relative vulnerabilities to climate change. This assessment could be particularly important in the context of building management systems or smart grid implementation, e.g., whether there would be a greater degree of dependency on communications infrastructure, and evaluate the ability of the smart grid to facilitate system response and recovery of service during emergencies. Related topics needing study are the co-dependencies and vulnerabilities of the power sector and other sectors, such as fuel supply and the water sector.
- Develop effective protocols, procedures, and tools for considering climate-change-related risks in decisions to locate, design, and build energy infrastructure. Work with industry organizations to survey and assess existing best practices, risk-assessment models, and adaptation strategies. Environmental and social-welfare effects should be incorporated.
- Research the effectiveness of, and develop best management practices for, enhancing community resilience through the use of community power and distributed generation. Best management practices could include ownership and operating models and maintenance considerations. Consideration could be given to how measures would differ between low-density and high-density communities. Assess the opportunities for PV to provide power to communities during emergencies.
- Assess the climate vulnerability of systems and infrastructure necessary to support a future low-carbon economy.
- Assess the climate vulnerability of existing and potential future natural gas and liquid-fuel infrastructure. Include assessment of potential ways to increase the resiliency of this infrastructure.

7.2 Relevance to Other Research in the Region and the Nation

- The NYC Building Department could be consulted on these issues, as they have had recent experience with various adaptation options and their advantages and disadvantages (e.g., moving power systems from basements has its own problems).

8 Public Health

Demand for health services and the need for public health surveillance and monitoring will increase as climate continues to change. Heat-related illness and death are projected to increase, whereas cold-related death is projected to decrease. Increases in heat-related death are projected to outweigh reductions in cold-related death. More intense precipitation and flooding along the coasts and rivers could lead to increased stress and mental health impacts, impaired ability to deliver public health and medical services, increased respiratory diseases such as asthma, and increased outbreaks of gastrointestinal diseases. Cardiovascular and respiratory-related illness and death will be affected by worsening air quality, including more smog, wildfires, pollens, and molds. Vector-borne diseases, such as those spread by mosquitoes (West Nile virus) and ticks (Lyme, babesiosis, etc.), may expand or their distribution patterns may change. Water supply, recreational water quality, and food production will be at increased risk due to increased temperatures and changing precipitation patterns.

8.1 Research Focus

- Determine and quantify the costs, effectiveness, and benefits of built-environment adaptations in terms of public health. These are difficult to measure but needed, to encourage “preemptive” health adaptations such as green infrastructure. Included could be a better understanding of the benefits of reducing other pollution to aid in climate resilience from a health perspective, or examining methods and programs to enable local governments to complete health impact assessments that examine alternative adaptation measures or strategies.
- Determine the effectiveness of targeted public health communications intended to protect public health in a changing climate. This effectiveness is difficult to measure, and there is a need to identify cost-effective ways of doing so. Some areas, such as NYC, have looked at some of their own communication strategies, but there is still a research need for better ways to gather information to measure the effectiveness of strategies and audience targeting. Assess the adequacy of existing early warning systems and evacuation plans, and the effectiveness of employing alternative communications technologies in these systems
- Assess approaches for addressing urgent public health needs resulting from power outages associated with severe weather events, as these weather events are very likely to occur more often under future climate change.
- Conduct additional research regarding the degree to which climate change may be expected to increase incidents of rodent-, food-, and vector-borne illnesses in the Northeast. These diseases may increase under climate change, with changes in pest and pathogen distribution and survival, water-quality degradation (e.g., from more frequent combined sewer overflow [CSO] events), and potentially from other, poorly understood linkages (e.g., legionellosis and cloud cover).

- Conduct additional research regarding the degree to which climate change may increase bacterial contamination of shellfish species (e.g., through increased water temperatures, run-off), as well as how climate change and harmful algal blooms may affect shellfish populations and the corresponding effects on human health.
- Identify vulnerable populations to, and determine effective adaptations for, the short- and long-term psychological impacts of climate change. A well-being survey looking at indicators of depression to measure the population's response to a climate-related event finds a difference between pre- and post-event. This area is often overlooked in the field of climate research, but it is a real issue that needs more attention.
- Determine the capacity and resources required for local and State health departments to conduct priority climate change and health adaptations.
- Develop an enhanced climate surveillance system that integrates weather forecasts and syndromic surveillance data.
- Explore methods for developing local estimates of the public health impacts of climate change and weather-related morbidity using fine-scale data, considering data sources such as satellite and LiDAR. Conduct health impact assessments based upon existing local and national estimates of weather-related morbidity and mortality. Explore methods for integrating population projections into projections of the health impacts of climate change and extreme weather.

8.2 Relevance to Other Research in the Region and the Nation

- Research in this area needs to be coordinated with the climate-related work being done by DOH (e.g., vector-borne disease, impacts of extreme heat, Prevention Agenda) (https://www.health.ny.gov/environmental/weather/index.htm; http://www.health.ny.gov/prevention/prevention_agenda/2013-2017/).
- The New York climate and health research should be coordinated with the Centers for Disease Control and Prevention (CDC) and its Building Resilience Against Climate Effects (BRACE) grantees (http://www.cdc.gov/climateandhealth/BRACE.htm).
- Both the DEC Division of Water and the Hudson River Estuary Program (HREP) have done work on CSOs (e.g., needs assessment, CSO violations and water quality impacts).
- Cornell University's Water Resources Institute has done some work on water infrastructure and climate change (http://wri.eas.cornell.edu/).
- There could be an opportunity to collaborate with U.S. EPA, which conducts Health Impact Assessments. HIAs evaluate public health impacts of projects, policies, or plans in communities and can show what would positively impact health and what would negatively affect health. (http://www.epa.gov/healthresearch/health-impact-assessments) The Long Island Smart Growth Resiliency Partnership has sponsored education and training events on the use of HIAs in land use policy, planning, and projects. The NYSDOS has included HIA as an explicit eligible activity in its LWRP grant program.

9 Transportation

Low-lying transportation systems such as subways and tunnels, especially in coastal and near-coastal areas, are at particular risk of flooding as a result of sea level rise, storm surge, and heavy precipitation events. It is very likely that coastal flooding will become more frequent and intense due to sea level rise. Materials used in transportation infrastructure, such as asphalt and train rails, are vulnerable to increased temperatures and frequency of extreme heat events. Air-conditioning requirements in buses, trucks, and trains as well as ventilation requirements for tunnels will increase. Runways may need to be lengthened in some locations because hotter air provides less lift and hence requires higher speeds for takeoff. Requirements for salting and snow removal may decrease as precipitation occurs more often as rain than snow. Freeze/thaw cycles that disturb roadbeds may increase in some regions as winter temperatures rise. The Great Lakes may see a shorter season of winter ice cover, leading to a longer shipping season. However, reduced ice cover may result in an increase in "lake effect" snow events, which cause various transportation-related problems.

9.1 Research Focus

- Assess how climate change will reshape demographic and travel trends into, out of, and within New York State by the end of the century. How would large-scale demographic trends driven by large-scale changes in ecosystems and water resources affect New York State? How would land use and freight movement change? Given the number of variables affecting demographic changes and the uncertainty associated with each of these variables, teasing out the climate impacts is difficult. However, such a study could be scenario driven, focusing on the most robust or impactful scenarios, or perhaps determining which adaptation strategies would be the most useful across the most scenarios. Such an approach could lead to prioritization of strategies, or thinking through possible futures that haven't yet been considered.
- Identify drainage and bridge infrastructure that would be most vulnerable to losses from intense precipitation events, and identify what adaptation strategies would be most cost effective. Some of this work is being done in the NYC metropolitan region, but more is needed across the State. Considerations should include guidance on identifying watershed types and characteristics most prone to flash flooding and potentially most destructive to transportation infrastructure. Research should incorporate projected trends in rainfall intensities in New York State. Structures of special concern include those with known flood vulnerability from potential failure in the second half of their design life.

- Develop cost/benefit guidance for incorporating climate adaptation strategies into specific transportation projects and general design standards, including both public and freight transportation, as well as considering climate change during routine maintenance (e.g., increasing elevation of a railroad when ties are replaced). Particular data elements that would be of interest include the economic costs to businesses if a system goes down (e.g., if a bridge wasn't available, how would communities on either side be affected by the closure of the bridge) and an estimate of the impacted population. There is a need for a consistent way of measuring benefits and costs across agencies; therefore, a combined benefit-cost methodology project across sectors could be useful.

9.2 Relevance to Other Research in the Region and the Nation

- New York State Department of Transportation has done some preliminary work on methodology for CBA of adaptation strategies.
- As part of the Storm Hardening and Resiliency Collaborative, Con Edison is thinking through CBA of hardening, including the potential costs to NYC, not just to Con Edison itself. Their methodology may be relevant.
- The NYS Department of Transportation is working with the USGS and The Nature Conservancy to develop methods that encourage consideration of climate change in planning of future transportation infrastructure such as culverts and bridges (http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/explore/new-york-culvert-inventory.xml). Some of this work is also being done under the Lake Champlain FHWA pilot (https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/vulnerability_assessment_pilots/2013-2014_pilots/index.cfm).

10 Water

Rising air temperatures intensify the water cycle by driving increased evaporation and precipitation. The resulting altered patterns of precipitation include more rain falling in heavy events, often with longer dry periods in between. Increases in heavy downpours will cause an increase in localized flash flooding in urban areas and hilly regions. Flooding has the potential to increase pollutants in the water supply and inundate wastewater treatment plants and other vulnerable development within floodplains. Less-frequent summer rainfall is expected to result in additional, and possibly longer, summer dry periods, potentially impacting the ability of water supply systems to meet demands, as well as the quantity of flow needed to sustain some water bodies. Reduced summer flows on large rivers and lowered groundwater tables could lead to conflicts among competing water users. Increasing water temperatures in rivers and streams will affect aquatic heath and reduce the capacity of streams to assimilate effluent from wastewater treatment plants.

10.1 Streamflow

10.1.1 Research Focus

- Develop river flooding projections associated with regionalized changes in rainfall, storm intensities, and stream flows, to allow communities to better plan and prepare for flooding events. A better understanding of the relationship between rainfall and stream flows would contribute to this effort, which would be improved by increased quality of data in stream response to rainfall. Identifying gaps in stream gage data and expanding the stream gage program affordably, to ensure sufficient placement of gages in flood-prone areas, would give communities valuable information during storm events and would also provide data that could be used in developing flood projections. A two-step process of identifying priority locations based on highest risk and completing flood-risk mapping using the USGS Flood Inundation Mapping Program (http://water.usgs.gov/osw/flood_inundation/) would be an effective approach.
- Improve scientific information related to the hydrologic cycle and streamflow in high-elevation settings, and support the use of hydrologic data in conjunction with climate model projections, to improve information regarding flooding in these often-overlooked areas of the State. More research focusing on steep-slope areas in particular would be useful. Consider the consequences of earlier snow-melt and soil freezing due to the absence of snow cover.
- Develop low-flow projections associated with future changes in air temperature, streamflow, and evapotranspiration. Low streamflow such as during extended droughts can limit access to aquatic habitat by organisms whose life cycle is dependent on migration. Low streamflow is often also associated with warm stream temperatures, which are a source of stress to cold water species. These low-flow periods also pose a challenge to those responsible for providing a water supply to municipalities.

- Improve understanding of how altered streamflow could change the magnitude of the effects of deposited pollutants (Hg, N, S) and/or recovery trajectory of affected ecosystems. For example, perhaps snowmelt-driven episodic acidification will be less severe as snow cover decreases, or small wetlands could spend more time dry, affecting Hg methylation. There could be a change in the loss of base cations with more intense rain events.

10.1.2 Relevance to Other Research in the Region and the Nation

- New York State has proposed an expansion of rainfall gages in Schoharie County. In addition, the Canal Corporation is pursuing an increase in gages and flood modeling in its jurisdiction. The New York State Streamflow Estimation Tool that estimates discharge at ungaged streams and rivers could also be of assistance with the above efforts (http://ny.cf.er.usgs.gov/nyprojectsearch/projects/LK00-A42.html -- to be released soon).

10.2 Water Quality and Availability

10.2.1 Research Focus

- Evaluate possible future changes in groundwater recharge and stability across the State using long-term records of groundwater levels and streamflow records from representative regions. Potential alteration of groundwater recharge from climate change is of great concern with regard to groundwater resource viability. Recharge has not been evaluated on a statewide basis in New York—only locally in a limited number of studies. A better understanding of these resources and how climate change is affecting underground water reserves would be very beneficial for helping to understand water quality/quantity protection and in development/land-use planning. In particular, recharge estimates for upland areas of thin and thick glacial till are needed to obtain a present-day, spatial picture of recharge distribution across the landscape. This type of research could also inform how green infrastructure could help recharge underground water reservoirs and aquifers, or on the efficacy of decentralized water treatment. A first step would be a characterization of the hydrogeologic settings of the State with creation of a basemap upon which site-specific or watershed estimates of recharge could be applied. This work is especially needed on Long Island.
- Improve understanding of the interconnection of groundwater and underground surface-connected water as well as water diversion and piped/engineered movement through cities. Detailed information on underground water infrastructure would be beneficial, and could be used for improved understanding of how to align with natural systems (e.g., stream daylighting).

- Improve understanding of changes in groundwater levels associated with changes in hydrology under future climate, and potential impacts of these changes. Much of the current infrastructure is generally "tuned" to hydrologic conditions over the last 50 to 100 years. Increases in groundwater levels may flood infrastructure such as basements and sewer lines. These effects could be localized or more regional in nature. Sanitary sewers and combined sanitary/stormwater sewers may experience increased flows because of infiltration of groundwater from rising water tables. These changes may in part be masked or made worse by increases in impervious surface area where development is ongoing. Changes in future hydrology that instead decrease groundwater levels could be a concern for water suppliers and for maintenance of baseflow in streams for ecological needs.
- Conduct research to better characterize and project future water availability, human use, and ecosystem requirements. As the climate changes, availability of water resources may change; this information is necessary for determining the best use of those limited resources in the future, and could help with water-withdrawal permitting decisions. An important piece of this research would be future water availability and use from the perspective of New York State agriculture and how fertilizer use could change. For example, if switching to a drought-resistant crop, would fertilizer needs change as well?
- Improve information on the frequency and severity of droughts under future climate change, and develop strategies to adapt. Information on groundwater and surface water flows, as well as related data such as evaporation rates, will be beneficial in determining how we adapt to drought (e.g., will we need to store more water in the future).
- Improve understanding of the vulnerability of private (including private water wells) and public drinking water supplies and water infrastructure, given population and climate projections. As populations shift and water availability changes under climate change, a better understanding of water supply will be critical, as well as strategies to adapt. This research is relevant to Focus Area 2 of the DOH Prevention Agenda (https://www.health.ny.gov/prevention/prevention_agenda/2013-2017/plan/healthy_environment/focus_area_2.htm).
- Assess how climate change could impact water supply through increased eutrophication and harmful algae blooms. Elevated levels of phytoplankton can be problematic to water treatment by clogging filters, increasing treatment costs and efforts, causing taste and odor complaints, producing toxins and decreasing public confidence in the water supply. Aspects of this work could be to establish baseline conditions as they exist today for parameters such as nutrient levels, turbidity, chlorophyll a, harmful algal blooms, phycocyanin, temperature, and pH of waters used for drinking water.
- Related research could include a better understanding of contaminants such as pharmaceuticals as they relate to flooding of wastewater treatment facilities or reduced dilution during droughts.

10.2.2 Relevance to Other Research in the Region and the Nation

- The New York State Museum geology group, Cornell University's Water Resources Institute, and the USGS should be consulted on any existing research or data available for these research items.
- The NYS RISE initiative has a number of ongoing projects that may relate to this research, including flooding impacts on wastewater infrastructure and flooding impacts on freshwater distribution systems (http://nysrise.org/news/).
- DOH is working on a project relating to vulnerabilities of private wells.

10.3 Infrastructure

10.3.1 Research Focus

- Identify dams that, if removed, could most reduce upstream flooding impacts and best contribute to ecosystem restoration and safety from catastrophic failure. Develop a strategic dam removal program to reduce flood vulnerability. As the climate changes and potential flood events may become more frequent, efforts to reduce vulnerability become increasingly important. Better information on how an upstream reservoir behaves would improve modeling that would help determine whether or not a dam contributes to flood vulnerability. There is also a need for protocols/best practices for dam removal in the State.
- Also lacking is a consistent methodology to understand the relative costs/benefits of flooding upstream with the presence of a dam versus potential flooding downstream upon removal of a dam, including dams that produce electricity.
- Review State dam safety criteria and associated flood inundation zones to ensure that they are adequate under extreme weather scenarios and climate change, incorporating changing streamflows as well. Increasing these criteria will typically increase downstream flooding—research needs to be conducted to determine if there are ways to increase dam safety without increasing downstream flooding. There is some work being done nationally in this area by FEMA, but the potential designs need independent testing in New York State.

10.3.2 Relevance to Other Research in the Region and the Nation

- The Hudson River Estuary Program, the New England Interstate Water Pollution Control Commission (NEIWPCC), and The Nature Conservancy have done some work in the Hudson River Estuary watershed on the impacts of dams and dam removal on species of greatest concern. This work should be consulted for potential synergies (www.dec.ny.gov/lands/4920.html).
- FEMA issued *Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams* in 2013 (https://www.fema.gov/media-library/assets/documents/3898), which may have implications for New York's dam guidelines.

10.4 Green or Nature-Based Infrastructure

10.4.1 Research Focus

- Develop benefit-cost analysis tools to determine where the implementation of natural and nature-based infrastructure to manage rainwater is most cost effective at the site level, including construction/maintenance costs versus damage costs. These tools should take a holistic view of performance, including environmental, social welfare, and health effects as well as economic. At a minimum, they should include the most recent Council on Environmental Policy's *Principles and Requirements* criteria for federal agencies (http://www.whitehouse.gov/administration/eop/ceq/initiatives/PandG). More-frequent downpours are likely to be a result of climate change, so efficient rainwater management is critical. Research could include modeling strategic placement of green or nature-based infrastructure options such as constructed wetlands or permeable pavement, as well as developing estimation and modeling capabilities to determine how much natural or nature-based infrastructure is needed in a given watershed to moderate flood flows now and under a changing climate. Ecosystem services and other externalities should also be considered.
- Develop models to estimate the cumulative effects of the installation or alteration of traditionally engineered and nature-based flood infrastructure in a given watershed, and a methodology to pinpoint the best places in a community to install green or nature-based infrastructure, improve groundwater recharge, etc. Assessment of the flooding impact of comprehensively implementing green or nature-based infrastructure in a particular sub-watershed would also be beneficial.
- Develop a monitoring framework to track and evaluate the resiliency of natural and nature-based infrastructure to manage rainwater over time. Research into the useful lifespan and long-term maintenance of particular types of green or nature-based infrastructure and their effectiveness in storing/recharging groundwater would be beneficial. Cornell University has done some monitoring of greenhouse gas emissions of these types of structures if not designed appropriately for a particular site; continuation of this monitoring would be beneficial (https://wri.cals.cornell.edu/research-topics/sustainable-water-infrastructure/stormwater).

10.4.2 Relevance to Other Research in the Region and the Nation

- Cornell University's Water Resources Institute has done some work on rainwater capture practices on their campus and tracking chemistry through such systems (http://wri.eas.cornell.edu/). Other states may already require modeling of implementation of green or nature-based infrastructure for site development. This work could serve as a resource for this type of research in New York State.
- HREP is undertaking some modeling and mapping projects to understand where green or nature-based infrastructure has been implemented and how water is moving through system. Onondaga County in New York State and the cities of Philadelphia and Denver have initiated green infrastructure programs to reduce the costs associated with stormwater management, and early work has been done on estimating stormwater management benefits; this work should be looked at when considering benefit-cost analysis.
- The Trust for Public Land, City of New York, Columbia's Center for Climate Systems Research, and CCRUN are in the midst of a project addressing green infrastructure and coastal protection for Staten Island and Jamaica Bay. The project includes an assessment of green or nature-based infrastructure performance during Superstorm Sandy, modeling future scenarios for coastal threats, and creation of an online geographic information system (GIS) tool that can help select sites for green or nature-based infrastructure projects.

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