New York State Energy Research and Development Authority

NYSERDA Environmental Research Program Plan

Research Area 1: Ecological Effects of Deposition of Sulfur, Nitrogen, and Mercury

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

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NYSERDA Environmental Research Program Plan

Research Area 1:

Ecological Effects of Deposition of Sulfur, Nitrogen, and Mercury

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1 EMEP Program

Under the New York State Energy Research and Development Authority (NYSERDA's) Environmental Research Program, the Environmental Monitoring, Evaluation, and Protection (EMEP) Program is in the midst of its third comprehensive planning effort. This plan builds upon the previous EMEP research plan, which was conducted in 2006 with the assistance of the New York Academy of Sciences. 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 results of these meetings are currently being compiled, and each component of the research plan will be made available upon completion. 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 EMEP program may be found at http://www.nyserda.ny.gov/Energy-and-the-Environment/Environmental-Research/EMEP.aspx

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's sensitive ecosystems and vulnerable populations. The EMEP program's strategic objectives include supporting:

- Energy-related environmental policy accountability through analysis of long-term monitoring records and modeling.
- Research that will enhance the understanding of the source types, source regions, and specific pollution components contributing to major energy-related environmental problems in New York State.
- Efforts to examine the health and ecological co-benefits of alternative energy and technology solutions.
- An environmental research capability to better address the critical problems facing the State and region and to create opportunities for innovation.

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 re-visit, revise, and reconsider priorities within this plan to ensure that it effectively addresses the current and future environmental issues of concern.

2 Ecological Effects of Deposition of Sulfur, Nitrogen, and Mercury

The EMEP Program supports research to improve the scientific and technical foundation to respond to policy needs. Over the next five years, EMEP research on ecological effects of deposition of sulfur, nitrogen and mercury will be guided by the following policy-relevant questions:

- How have New York ecosystems been affected by, and how are they responding to, emission reduction policies associated with acidification and mercury pollution?
- How will current and anticipated international, national, regional, and local strategies to reduce SO_x, NO_x, and mercury emissions affect New York State ecosystems?
- Given financial resource constraints, how can New York State maintain an appropriate multi-media monitoring program that is sufficiently robust to identify impacts on ecosystems and track changes related to emissions policies?
- How will ecosystem responses to sulfur and nitrogen deposition and mercury be influenced by other concurrent environmental changes, such as invasive species and climate change?
- Are there practical options for accelerated recovery of ecosystems beyond emissions reductions? If yes, what are their costs and benefits?
- How does the impairment of New York's ecosystems from SO_x, NO_x, NH_x and mercury deposition impact New York State's ecosystem services and economy, and what are the potential economic benefits of environmental improvement strategies?

3 Monitoring / Surveys / Synthesis

The processes of acidification and recovery take place over long time scales and involve various ecosystem compartments. New York State would benefit from additional data to evaluate landscape-scale or whole-ecosystem changes from decreased levels of acidic deposition and mercury. For example, there is some information on lake chemistry, but information is more limited on other ecosystem components, including both terrestrial and aquatic biota. Furthermore, information that evaluates how aquatic systems, including lakes, streams and wetlands, terrestrial systems with particular emphasis on forest vegetation (e.g. forests and soils with their respective biota) are responding to decreased deposition is limited.

In 2012, EMEP completed an "Assessment of Long-Term Monitoring of Nitrogen, Sulfur, and Mercury Deposition and Environmental Effects in New York State."[1] NYSERDA developed this stakeholder-driven effort to find greater efficiencies, gaps, and redundancies in monitoring that are responsive to changing policies and research needs. NYSERDA presented this assessment to a stakeholder group for feedback on July 26, 2012, and finalized the report in November 2012. Policymakers should consider its findings when making changes to New York's deposition network and monitoring activities.

3.1 Deposition Monitoring and Trend Analysis for Sulfur, Nitrogen, and Mercury

To be effective, deposition monitoring programs must provide high-quality, reliable data that inform current scientific and/or policy questions and issues. Deposition monitoring networks are most effective when the data are collected using consistent instrumentation and methods over broad geographic areas. This consistency allows for mapping and modeling of measured results across multijurisdictional boundaries and landscape features. With changing policies and advances in scientific understanding, these monitoring networks and the data they generate should be reassessed periodically to optimize their value and effectiveness.

For more than 25 years, DEC's Division of Air Resources (DAR) operated an acidic-deposition-monitoring network in 20 locations across New York State. DAR supported weekly collection and analysis of wet-deposition chemistry as well as a number of air quality parameters. This program recently merged with the National Atmospheric Deposition Program's (NADP's) National Trends Network (NTN).

EMEP has traditionally supported a number of deposition monitoring activities, either directly (contract 6818), through other monitoring activities (contracts 4915 and 25352), or as components of more focused research projects

[1] http://www.nyserda.ny.gov/Publications/Research-and-Development-Technical-Reports/Environmental-Reports.aspx

(contracts 10659 and 10660). Syracuse University (contract 10659) is also developing estimates of mercury deposition to the Adirondacks based on models (e.g., Big Leaf) and experimental and deposition data.

3.1.1 Research Focus Going Forward

- Support ongoing long-term deposition monitoring efforts and adaptation of the networks to facilitate robust temporal trend and spatial analyses. Atmospheric deposition networks provide the best sources of information on what is actually being deposited on New York State.
- Expand dry deposition monitoring, including base cations, where possible. Dry deposition monitoring is relatively limited in New York State and the monitoring of base cations critical to the recovery of ecosystems from acid deposition is largely unknown.
- Evaluate the full extent of mercury and acidic deposition on New York's most sensitive and unique ecosystems, such as alpine systems and Pine Barrens. Relatively little information on acidic and mercury deposition exists for these types of ecosystems.
- Support research to develop the appropriate NAAQS and Aquatic Acidification Index. The U.S. Environmental Protection Agency (EPA) has included the Adirondack Park as a pilot location in the development of the EPA's final National Ambient Air Quality Standard (NAAQS). The DEC worked with the EPA to identify and monitor three sites that provide a south-west to north-east transect across the Adirondack Park, representing a range of acidified regions of the Park.
- Conduct research to understand the best monitoring method for SO_2 at ambient concentrations going forward in an effort to address two key questions: Is the dry deposition velocity of SO_2 linear over the concentration ranges 0.1-10 ppb; are concentrations driven by peak short-term (one hour) events or longer-term average (week, season, annual) atmospheric concentrations, and; how important are surface characteristics in affecting dry deposition velocities at low SO_2 concentrations? Annual average SO_2 concentrations have been steadily decreasing and now average below one part per billion (ppb), which is very close to the measurement detection limit for the Federal Reference Method (FRM) for continuous SO_2 measurement. Ambient SO_2 varies substantially over short time scales, and this variation is not captured by the Clean Air Status and Trends Network (CASTNet) filter pack data that are collected on a weekly basis.

3.1.2 Relevance to Other Research in the Region and the Nation

Acid and mercury deposition continues to affect ecosystems in New York State (e.g., Adirondacks, Catskills). Scientists need information compiled through monitoring to assess the comprehensive impacts of deposition as well as response and recovery rates from emissions reduction efforts.

NADP is a member-supported deposition network, and program participants fund its operating costs. By applying and following the program's Quality Assurance Plan, any organization can participate. Many regulatory and environmental entities (e.g., DEC, EPA, Environmental Defense Fund) use the resulting information on temporal trends and spatial patterns of atmospheric deposition of pollutants for basic and applied scientific analyses and to provide accountability for policy changes.

NADP is comprised of five separate sub-programs, and each fulfills a different role:

1. The National Trends Network (NTN) determines the chemical concentrations and deposition of precipitation on weekly samples.
2. The Mercury Deposition Network MDN provides mercury concentrations in precipitation and deposition from weekly samples.
3. The Atmospheric Mercury Network (AMNet) provides continuous collection of dry and gaseous atmospheric mercury in conjunction with MDN wet mercury deposition.
4. The Atmospheric Integrated Research Monitoring Network collects daily single-event deposition chemistry.
5. The Ammonia Monitoring Network continuously monitors ambient ammonia concentrations.

In addition, EPA's Clean Air Markets Division administers and operates the CASTNet, which is a national long-term environmental monitoring program. A single contractor conducts its chemical analysis. CASTNet was established in 1991 under the Clean Air Act Amendments to assess trends in acidic deposition as a response to emission reduction regulations such as the Acid Rain Program and NO_x Budget Trading Program. CASTNet has since evolved to measure concentrations of both wet and dry air pollutants involved in acidic deposition affecting regional ecosystems and rural ambient ozone levels. CASTNet is not synonymous with any combination of NADP sub-programs. Today, three CASTNet sites operate in New York State (Huntington Forest in the Adirondacks, Ithaca in central New York, and Wildcat Mountain near Biscuit Brook in the Catskills).

Based in part on the "Assessment of Long-Term Monitoring of Nitrogen, Sulfur, and Mercury Deposition and Environmental Effects in New York State", DEC recently merged the Acid Deposition Network into NADP's NTN. This transition combined relatively collocated sites, expanded NTN sites where appropriate, and closed a few sites where data needs were less pressing. DEC continues to support mountain cloud chemistry monitoring at the summit of Whiteface Mountain from June through September. Additionally, DEC operates approximately 20 continuous SO_2 air monitors across New York State.

Mercury deposition monitoring has been much more limited in New York State than acid deposition monitoring. Today, three AMNet sites operate in New York State (Rochester, Bronx, and Huntington Forest). AMNet collects continuous data relating to gaseous and particulate mercury. It is the most costly to operate and most technically rigorous of the NADP networks. Wet deposition (snow and rainfall) is collected through MDN. Four MDN sites operate in New York State, with a fifth expected to come on-line in the spring of 2013 (Cedar Beach on the eastern end of Long Island). An additional site at West Point in the Hudson Valley shut down in 2010 due to lack of funding.

3.2 Multi-Media Monitoring and Trend Analysis for Sulfur and Nitrogen

Emissions of sulfur and nitrogen compounds from combustion sources, including fossil-fuel power plants, are precursors to acidic deposition, which can adversely affect the health and productivity of ecosystems. How reducing these emissions allows ecosystems to recover, recovery, and the extent to which reductions correlates to recovery rates are not well understood. For example, surface waters in the Adirondacks have shown less recovery than was anticipated in response to decreases in emissions of acid-gas compounds. To establish environmental trends with confidence, to provide decision-makers with the information they need to evaluate the effectiveness of current public policy, and to provide a sound scientific basis for future decision-making, scientists need a much better understanding of how emissions reductions relate to ecosystem response.

To this end, EMEP has supported monitoring and trend analysis on lakes (contracts 4915 and 25352); streams (contracts 4915A, 25552, 7613, 16295, and 16299); and through ad hoc soil surveys and re-surveys (contracts 16299). The recent release and extension of the Adirondack Effects Assessment Program (AEAP) and associated data set (contract16298) has added a needed aquatic biota component to lake sampling. The Adirondack Stream Surveys (contract7613 and 16295), which have been coupled with soils sampling, have helped inform missing linkages between soils and stream chemistry. In addition, EMEP-sponsored studies that are evaluating the acidification of the Tug Hill Plateau (contract 8646) and a new project assessing the acidification (contract 28431) and mercury (contract 25929) impacts on the Suffolk County Pine Barrens will help assess the spatial extent of acidification beyond the Catskills and Adirondacks.

These activities are providing the scientific and policymaking communities with the information and analyses to better understand soil, stream, and lake acidification and their recovery through trends analysis across multiple media. Yet even with these activities many data gaps exist. For example, little is known about changes in fish assemblage in acid stressed and recovering streams, our understanding of changes in soil chemistry (e.g. nitrogen pools) across New York State is very limited, and there is a dearth of multimedia monitoring of mercury deposition. To untangle the complex biogeochemical processes, these analyses often call for additional sampling and more intensive investigations.

3.2.1 Research Focus Going Forward

- Prioritize stream sampling in the Adirondacks for additional long-term monitoring of both hydrology and chemistry and include three levels of monitoring intensity: index streams, routine chemistry monitoring, and periodic extensive surveys. Include soil monitoring at coordinated ecosystem monitoring sites, especially in relation to stream chemistry to allow for a better understanding of belowground biogeochemical dynamics. The response to declines in acidic deposition may be less marked in lakes than streams due to their higher buffering capacity and the neutralizing effect of within-lake processes during retention. Due to the close coupling of shallow groundwater flow paths for small streams, soil conditions, and below ground vegetation systems, stream chemistry can help provide an indicator of ecosystem response to decreased deposition and recovery from acidification.

- Conduct new toxicity tests that link aluminum chemistry to mortality data in previously assessed streams to provide some measure of potential recovery from toxic-aluminum effects in Adirondack streams. Dissolved organic carbon is increasing in many Adirondack waters, which may be exacerbating mercury bioaccumulation. Inorganic monomeric aluminum concentrations are strongly and inversely related to DOC concentrations in Adirondack streams; thus toxicity, even at unchanged pH and total aluminum levels, may be declining substantially in Adirondack streams.
- Evaluate the role of wetlands within watersheds in affecting different responses (e.g. DOC protection from inorganic monomeric aluminum) with respect to spatial and temporal patterns in the recovery from acidification. This effort will be especially important in the Adirondacks where wetlands comprise an important component on many of the watersheds.
- Continue surveys to monitor Adirondack lake biological recovery. Research examining changes in fish populations associated with decreases in acidic deposition has demonstrated that lakes in the region have not made clear whether there has been systematic progress toward recovery. These populations do not require annual data collection, so sampling on a rotating basis could be an appropriate strategy.
- Conduct research and monitoring that characterizes the current status, extent, and severity of acidification impacts; key drivers and relations (models); and the potential for recovery of resident fish assemblages in acid-sensitive streams of New York. Due to their complexity and high variability, stream ecosystems are some the least understood and studied, but they are some of the most severely acidified aquatic systems in parts of New York State. Some work on stream periphyton and macroinvertebrate communities has been completed; however, the effects of acidification on charismatic macrofauna (such as brook trout) and entire stream-fish communities are lacking.
- Monitor phytoplankton, zooplankton (rotifers, crustaceans, and copepods), periphyton, and macroinvertebrates to help understand trends in species richness, community composition, and the appearance and disappearance of important indicator species in connection with changes in water chemistry, such as recovery from acidification. These data can provide the first biological indicators of chemical recovery; and, as such, they are needed to understand the condition trends in aquatic biota.
- Explore, in depth, the role of declining soil calcium levels in the Adirondacks and Catskill mountains in altering these systems and in decreasing neo-tropical songbird populations. Calcium loss from terrestrial systems may be causing changes in plant growth/health especially for some tree species such as sugar maple. In addition, the population of terrestrial fauna (i.e., microorganisms, isopods, caterpillars, etc.) and the organisms that feed on them, namely songbirds, may be influenced by calcium availability.
- Test and deploy environmental sensor technology and wireless communication tools to aid in the understanding of real-time ecological processes and how acidic deposition and mercury affect ecosystems. Advances in these tools present an opportunity to deploy sensor networks to monitor key environmental conditions over a broad landscape. Such sensors may be especially important for understanding the effects of short-term events, or to measure subtle changes in conditions across a landscape that would be too costly with traditional methods.
- Continue research into cloud water chemistry and its effects on high-elevation ecosystems to better chart how to protect these systems. Compared with precipitation, cloud water exhibits substantially higher concentrations of major ions. Cloud water chemistry is believed to play a major role in the acidification of sensitive, high-elevation ecosystems.
- Further compare the measurements and predictions derived from different monitoring and modeling efforts including NADP/NTN, CASTnet, and Community Multi-scale Air Quality (CMAQ). The CMAQ model has been developed by the EPA and is being used extensively for a number of predictions at various temporal and spatial scales.

3.2.2 Relevance to Other Research in the Region and the Nation

In cooperation with the DEC and EPA, the Adirondack Lakes Survey Corporation (ALSC) continues to monitor Adirondack lakes as part of the Adirondack Long-Term Monitoring program (ALTM). ALTM resurveys fisheries in its 52 lakes and conducts limited episodic sampling during high-flow events. ALTM also conducts annual sampling in 43 lakes in cooperation with EPA's Temporally Integrated Monitoring of Ecosystems Program.

AEAP's long-term biological monitoring of 32 Adirondack lakes has been reduced to 16 lakes, two times per year. The program is working on making data of the past 18 years available via publications and reports. Plankton data are currently being used to develop critical loads models.

ALSC and the U.S. Geological Survey monitor Buck Creek, Bald Mountain Brook, and Fly Pond. The State University of New York College of Environmental Science and Forestry (SUNY ESF) monitors the Arbutus Lake inlet and outlet at Huntington Forest as well as two sub-watersheds. The Western Adirondack Stream Survey was an experimental design and test of a stream survey strategy in a large (400,000 ha) landscape. During 2003-2005 the USGS led a team to survey 200 streams during five hydrologically sensitive time periods. The survey design was efficient, providing the first large-scale stream assessment linking terrestrial (soils), stream (chemistry, diatom, and macroinvertebrate assemblages), and lake chemistry signals. The East-Central Adirondack Stream Survey has expanded this survey design (2010-2012) to other parts of the Adirondack Park.

In the Catskill Mountains, USGS continues to monitor four streams for continuous flow, and conducts biweekly and periodic event sampling as part of EPA's long-term monitoring. The steering committee for the biennial Catskill Environmental Research and Monitoring Conference has been working to develop a web-based bibliography and data catalog for Catskills-based research. Additionally, the group is moving forward with developing plans for a Catskill Research Forest and better research coordination of research and monitoring efforts.

3.3 Multi-Media Monitoring and Trend Analysis for Mercury

Monitoring of the various mercury chemical species in ambient air is inconsistently applied. How other pollutants affect the dry deposition of mercury and the fate of total annual atmospheric emissions of mercury is difficult to determine, as is the variation of dry and wet deposition of mercury. Speciation of the ambient concentrations of mercury and dry-deposition measurements are important for source attribution and assessment as well as improvements in predictive models; however, no standardized protocols for measuring speciated ambient concentrations of mercury exist, and there are no easily deployable methods to measure dry deposition directly.

To address these concerns, EMEP is conducting a comparison of multimedia monitoring options for mercury (contract 10659). This research is assessing and comparing surrogate surfaces for the collection of dry mercury deposition. Each resulting new technique is likely to offer its own strengths and weaknesses. Accurate characterization of mercury deposition will likely continue to be difficult for the foreseeable future. Along with DEC and the Great Lakes Commission, EMEP is helping to support an AMNet site at Rochester (contract 24012) and is working with SUNY ESF (contract 31250), Clarkson (contracts 26578 and 30460), and DEC to maintain an AMNet site at Huntington forest, two of only three in New York State. DEC maintains a third site in the Bronx. AMNet provides measurements of atmospheric mercury concentrations of gaseous oxidized, particulate-bound, and elemental mercury. These estimates are coupled with MDN sites, which provide wet deposition measurements. Together, these provide the best calculations of mercury deposition.

As mercury emissions from various sources around the world change, the species and sources of mercury deposited in New York State will likely shift. Mercury emissions policies in New York State, across the country, and around the world influence deposition in New York State. It is important to understand how these different sources affect deposition and how those contributions affect the State's ecosystems. A pilot project with the Biodiversity Research Institute is seeking to determine if stable isotopes of mercury in bird blood samples can be used to identify the sources of the mercury (contract 30388).

3.3.1 Research Focus Going Forward

- Conduct further research on the quantification of the factors affecting dry deposition velocities and surrogate monitoring methods to incorporate into models of total and dry mercury deposition. Wet deposition of mercury is easier and less expensive to monitor than air concentrations or dry deposition. The measurement of dry deposition is a two step process in which air concentration data are converted to deposition by the use of deposition velocities. Though wet and dry deposition tend to show similar trends, dry deposition comprises a large portion of total deposition and may be more spatially and temporally variable than wet deposition in New York State.
- Establish a model of dry-only deposition based on dry mercury deposition in litterfall for both long-term monitoring and short-term research projects. Mercury in litterfall may serve as a proxy for dry mercury deposition because mercury deposited in particulate and gaseous forms adheres to leaves. While annual litterfall mercury deposition only approximates the lower bound of annual dry mercury fluxes, measuring litterfall is much more cost-effective than other methods.
- Develop and refine emerging techniques that quantify the natural abundance of mercury isotope ratios in environmental samples to give new insight into the origin of mercury in an ecosystem. Determining sources of mercury pollution in ecosystems is complex but increasingly important and feasible.

3.3.2 Relevance to Other Research in the Region and the Nation

Measures to reduce mercury emissions are being implemented by fossil fuel fired electrical generation power plants under EPA's Mercury and Air Toxics Standards. Under the guidance of the United Nations Environment Programme, a global mercury treaty has been under development since 2010, and the final document will be open for signature in the fall of 2013. To understand the ecosystem response to reductions in mercury deposition, it is important to know how much is being deposited, how much is being re-emitted, and to what extent the legacy mercury load in soils and watersheds will be the drivers in mercury bioaccumulation in terrestrial and aquatic food chains.

NADP recently completed a pilot program and is implementing a litterfall mercury monitoring program to complement MDN and AMNet. This pilot has evolved to be an official NADP program that provides a way to collect measurements to approximate a large part of the mercury dry deposition in a forest landscape in a consistent manner across the country. Various entities, including EPA and NADP, are working to standardize methods for speciated monitoring (e.g., for Tekran). These entities are establishing protocols on data collection and standardizing measurement procedures so that the same methodology can be used across the network to facilitate data sharing and comparisons.

4 Mercury in Biota

Current information is not sufficient to determine the full extent to which biota, fish and wildlife in particular,have been affected by, are recovering from, or how they are responding to changes in the deposition rates of mercury, nitrogen, and sulfur. Monitoring is needed to address information gaps that prevent determining how bioaccumulation may be linked to emissions or depositional changes. Additionally, baseline data is needed to understand the extent of biological contamination in different regions and ecosystems. With a reliable, continuous dataset for bio-indicators of mercury exposure, scientists can develop a consistent benchmark. This would allow more effective tracking of changes in mercury concentrations in selected biota in a consistent manner over time.

EMEP has supported the monitoring of mercury levels in Adirondack common loons for nearly a decade (contracts 7608 and 27965). Results show that mercury is a primary anthropogenic stressor and results in a lower population growth rate than modeled results project. EMEP has also supported fish surveys and re-surveys for mercury (contract 7612) across the State and continues to support ALSC's re-sampling of Adirondack fish (contracts 4915 and 25352), which includes mercury analysis. DEC has continued to survey mercury concentrations in fish in New York State waters, with a focus on State parks, although sampling has been somewhat limited by budget constraints. In addition, EMEP has conducted a number of passerine bird surveys, which have included their food sources and, in some cases, stable isotope mapping of food webs (contracts 7608, 16296, 22258, 19881, PO 9956). Researchers have collected samples from a variety of habitats including hardwood forests, bogs, boreal forests, mountain sites, and coastal salt marshes at various locations in New York State.

EMEP is sponsoring an effort to survey birds and their food sources in the Pine Barrens of Long Island (contract 25929) in conjunction with an evaluation of acidification status (contract 28431). These habitats have characteristics that make them susceptible to high levels of mercury bioaccumulation, such as high mercury deposition rates, low soil buffering capacity, and fluctuating water levels. A pilot project (contract 30388) is using residual bird blood samples from this project (contract 25929), along with bird blood samples from previous projects (contracts 16296 and 22258) and new prey samples, to determine whether stable isotopes of mercury in bird blood samples can be used to identify mercury sources. This technique could help identify which mercury sources pose the greatest risk to wildlife.

Scientists are now beginning to understand the extent of mercury accumulation in wildlife, but more work remains. For many organisms, the body burden of mercury that begins to affect behavior or reproductive success is not fully understood. Mercury data from loon recaptures over time have shown that some individuals have declining mercury levels, while others have increased mercury body burdens (per personal communication N. Schoch 2012). Similarly, trends of mercury in inland lake fish generally show declines over time, but the results are mixed, with some inland lakes increasing while others are decreasing. This inconsistency is likely due to the variety of factors that affect mercury bioaccumulation in individual organisms. Better methods, longer-term data collection, and more data in general are needed to identify and evaluate trends in biotic mercury levels. These trends are critical to informing policy makers of the benefits of regional and national mercury emissions reductions. Additionally, research regarding the extent to which legacy mercury in soils will move into the food chain would help policy makers understand how quickly changes in mercury emissions affect wildlife.

4.1 Research Focus Going Forward

- Support diverse biological monitoring for mercury to illustrate how emissions policies are affecting wildlife within the State. This monitoring also will provide better information to consumers (e.g., fish-consumption advisories). Sampling diverse groups of organisms, and their environments, over time will help clarify spatial patterns and temporal trends in mercury bioaccumulation and how environmental factors influence mercury methylation. The identification and use of index organisms may aid in this effort.
- Conduct large-scale, systematic measures of mercury levels in fish in Hudson River Estuary, the New York Bight, Long Island Sound, and in fish caught commercially. Assess mercury's impact and trends in fish in these systems, both spatially and temporally. Traditionally, studies and monitoring programs looking at mercury levels in fish have been conducted in freshwater systems.
- Conduct follow-up studies to monitor the long-term trends of mercury concentration levels in loons Continue monitoring loon populations and mercury levels to provide insight into mercury levels and how changing mercury emissions affect wildlife behavior and population dynamics. Mercury deposition has had a detrimental impact on the health of common loon populations. Some short-term monitoring studies have reported that the concentration of methylated mercury in loons decreased by up to 50 percent when sources of mercury pollution were eliminated.
- Conduct research to better understand these interrelationships and how emissions policies affect wildlife and share results with policy makers. Researchers have found a correlation between increased methylmercury levels in fish tissue and increases in dissolved organic carbon (DOC) in the water. Similar correlations have been found with common loon bioaccumulation and the pH of their nesting lake. As a result, changes in deposition do not necessarily translate to similar changes in the bioaccumulation at all locations.
- Re-sample the 2003-2005 fish mercury survey conducted by Simonin et al. (2008) to detect changes in both fish and surface water mercury concentrations over the last decade and to help refine current models of fish mercury concentrations.
- Conduct additional research to help determine the best use of aquatic invertebrates in food web linkages for fish in mercury surveys. Measurements of mercury and methylmercury tissue concentrations of aquatic invertebrates are often used as an indicator for mercury concentrations in the substrate in which the organisms live, as well as for studies of dynamics of mercury in food webs. These organisms may be a suitable, lower-cost proxy for higher-level organisms or for measuring mercury concentrations in water, which are often so low that they cannot be detected.
- Conduct periodic monitoring of mercury in terrestrial invertebrates to inform studies of a variety of other ecosystem components. Researchers can use tissue concentrations of mercury and methylmercury in terrestrial invertebrates as an indicator for mercury concentrations in the substrate in which the organisms live as well as for studies of dynamics of mercury in food webs. There is currently no long-term monitoring of terrestrial invertebrates, though some collections have been included in other food web studies.
- Repeat surveys of song birds and birds of prey every several years to track trends in deposition effects on bird populations and overall terrestrial ecosystem health throughout the state. Songbirds serve as good indicators of mercury in terrestrial ecosystems.

4.2 Relevance to Other Research in the Region and the Nation

DEC has been monitoring mercury in fish in New York State for decades. These data inform the New York State Department of Health (DOH) fish consumption advisories and aid in the development of trends in mercury bioaccumulation in aquatic systems, which can be related back to emissions reduction policies. Because of budget constraints in recent years, DEC's sampling efforts have slowed considerably; however, ALSC has continued to sample a limited number of ALTM waters each year for fish mercury.

As in aquatic systems, mercury concentrations in terrestrial animals increase as mercury moves through the food chain, but the transfer mechanisms are not well understood, and spatial patterns of mercury bioaccumulation in terrestrial systems are not well documented. Monitoring of mercury concentrations in songbird populations can help to determine temporal trends in mercury concentrations in terrestrial biota. New data are showing that some guilds (groups of species that exploit the same resources) of birds in different regions of the State have blood mercury levels high enough to cause physiological effects. In 2012, the Biodiversity Research Institute and the Nature Conservancy released "Hidden Risk: Mercury in Terrestrial Systems of the Northeast,"[2] which highlights the high levels of mercury contamination in songbirds and bats throughout 11 northeastern states, including New York.

NYSERDA's recently published report indicates that common loons in the Adirondacks with territories on acidic lakes had extremely high levels of mercury in their blood and decreased reproductive success. Population model results indicated that the portion of the Adirondack loon population exposed to high mercury levels has a reduced growth rate compared to birds with low body burdens of mercury. Continuing to monitor loon mercury levels and how mercury levels control population dynamics is important to gain a better understanding of how changes in emissions policies affect these organisms.

The Coastal and Marine Mercury Ecosystem Research Collaborative (C-MERC) recently release a series of papers and a summary report outlining the issues associated with marine mercury. Approximately 85 percent of the methylmercury exposure to the U.S. population is from consuming estuarine and marine fish that often exceed human health consumption guidelines. With increasing mercury emissions globally, these levels can be expected to rise.

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2 http://www.briloon.org/hiddenrisk

5 Synthesis and Reexamination of Data to Evaluate Acidic Deposition and Mercury Affects and Policies

Several baseline (synoptic and temporal) studies and many intensive studies have been conducted by researchers, especially in the Adirondacks and Catskills, to understand the processes of acidification and mercury cycling. While individual studies often include policy implications in their findings, more collective synthesis of research projects and long-term monitoring data will better inform policy.

Trend analysis for projects collecting monitoring data (e.g., ALTM and AEAP) is ongoing by a number of entities, and EMEP is sponsoring a synthesis of acidic deposition and mercury research, from deposition to eutrophication of coastal regions, which is scheduled to be complete in the fall of 2013 (contract 16300). Additionally, EMEP completed a reassessment of monitoring activities related to sulfur, nitrogen, and mercury in 2012 (contract 22951). This work has helped determine what could be expected if spatial or temporal monitoring activities are changed. It also identified areas and sampling media where coverage is insufficient, adequate, or redundant.

EMEP's Outreach Program (contract 21309) is designed to identify key policy makers and groups, the best channels to reach them, their informational needs, and the most appropriate formats to use to convey scientific findings and information. Reassessing the state of the science and policy through synthesis activities is helpful in assuring that the research questions and focus are policy relevant. Additionally, synthesis and reexamination of existing datasets and novel research approaches can provide an enhanced understanding by identifying linkages not seen within individual research projects. It can also extract additional value from data that has previously been collected.

5.1 Research Focus Going Forward

- Reanalyze datasets and synthesize multiple datasets to gain new understanding of ecosystem function and response to changing N, S, and mercury depositional loads. Reexamining existing and historic data could extract additional value and bring a greater understanding of ecosystem changes at minimal costs. Ecosystems are naturally dynamic and their individual components must be analyzed in concert. The integration of existing disparate datasets could be very helpful in increasing the understanding complex systems over both space and time.
- Narrow the gaps between ecological and social sciences research to accelerate the transfer of information from researchers to policy makers. Humans and natural ecosystems are inextricably intertwined. Natural ecosystems provide fundamental services upon which humans depend. These ecosystem services are the processes by which the environment produces resources that humans often take for granted such as filtering the air and water, flood control, timber, and habitat for fisheries. An increased understanding of human/ ecosystem interactions will aid in protecting natural ecosystems and the critical services they provide to humans.

5.2 Relevance to Other Research in the Region and the Nation

Long-term programs for lake water chemistry and biota (e.g. ALTM, AEAP) in New York do not generally integrate information they generate. A synthesis of research findings and datasets can improve the understanding of how acidic deposition has influenced water chemistry effects. Additionally, more information is needed to link soil, wetland, stream, and lake chemistry. Linkages between forest structure and the chemistry of wetlands, soils, and surface waters could be further explored in relation to the USDA Forest Service's Forest Inventory and Analysis and Forest Health Monitoring programs. In 2009, EMEP developed a synthesis of acidic deposition related impacts entitled "Actions and Response." This synthesis focuses on emissions policies and the environmental response.

Many other organizations have worked to synthesize information about mercury in the environment. In 2012, C-MERC issued "Sources to Seafood,"[3] a report that addresses mercury pollution in the marine environment. In 2013, the Biodiversity Research Institute and the International Persistent Organic Pollutants Elimination Network released "Global Mercury Hotspots,"[4] a report that discusses how fish is consumed around the world in spite of advisories warning against doing so because of elevated levels of mercury.

Finally, EMEP is completing a multi-disciplinary synthesis of published research findings on effects of acid and mercury deposition on sensitive ecosystems in New York State (Adirondack and Catskill Mountains, Great Lakes, estuaries, and coastal ecosystems). This project is building upon a wealth of EMEP-sponsored research and other research projects that have previously categorized, quantified, and advanced understanding of ecosystem processes related to atmospheric deposition of strong acids and mercury, nutrient and mercury cycling, element interactions and leaching, response of watershed ecosystems to changes in atmospheric deposition, and associated biological effects in aquatic, wetland, and terrestrial environments.

[3] http://www.dartmouth.edu/~toxmetal/assets/pdf/sources_to_seafood_report.pdf
[4] http://www.briloon.org/uploads/documents/hgcenter/gmh/gmhFullReport.pdf

6 Biogeochemical Processes and Ecosystem Response

After several decades of acidic deposition, surface waters in New York and the Northeast became more acidic, less productive, and higher in toxic metals such as aluminum and mercury. Soils have become more acidic and less fertile, and forests in many areas are showing signs of acidification-related stress. The acidification of surface waters can lead to declines in the fish population. Acidic water also affects aquatic plants and invertebrates eaten by fish. As a result, the entire aquatic food chain can be reduced, leaving a lake or stream less healthy, resilient, and productive. In addition, acidic deposition has altered the chemistry of soils across large areas of New York and the Northeast by causing the depletion of calcium and other nutrients, increasing the accumulation of sulfur and nitrogen, and mobilizing inorganic aluminum, which enters soil waters and, ultimately, surface waters.

6.1 Soil Processes and Recovery from Acidification

The base status of some sensitive soils has been deteriorating during recent years especially in some Adirondack watersheds, while the lake water chemistry has generally been improving. The availability of base cations in these sensitive soils is expected to continue to decline. This is important because the extent to which acid-sensitive lakes continue to recover is tightly coupled with soil processes; moreover, further deterioration of soil base conditions could contribute to adverse impacts on vegetation. Recent research and sampling efforts have begun to bridge important information gaps regarding the relationship between soil conditions and surface water chemistry; however, some critical questions remain, particularly in relation to forest responses to changes over time in soil base status. Further research is needed to ascertain how changes in soil conditions over extended periods impact lakes, streams, wetlands, forests, and other ecosystem components and on forest response to the offsetting effects of varying degrees of declining acidic inputs and continuing base cation depletion.

EMEP's research on soil processes is ongoing and has included interactions between carbon, nitrogen, and calcium (PO9955) linkages between DOC and NO_3 export (contract 10662) and the impacts of weather and climate on biogeochemistry and sulfate export (contract10661). A stream survey in the Adirondacks (contract 16295) seeks to link soil chemistry and stream chemistry, while a separate project is assessing similar links in the Catskills (contract 16299). Projects have also been funded to assess linkages between forests, soils, and stream chemistry (contract 10660). Additionally, a recently completed project evaluated different computer modeling techniques to assess aluminum mobilization in streams as it relates to recovery from acidic deposition in the western Adirondacks (contract 10658). In general, research has moved from an early focus on aquatic systems, primarily lake assessments, to a greater emphasis on streams, soils, and forest interactions.

6.2 Research Focus Going Forward

- Develop stronger links between the ecosystem health of forests, soils, wetlands, streams, and lake structure/health. Stream chemistry indicators of soil and forest health conditions would aid in the development of stronger mass balance or dynamic models describing, among other things, the loading and unloading of nitrogen in soils.
- Conduct research on microbial activity to help determine how it affects soil chemistry/quality, biogeochemical processes and acidification. Collect more information on microbial biodiversity, microbial activity, and how microbes affect and are affected by soil chemistry/quality, biogeochemical processes, acidification, and TMDL data.
- Research and document observed delays in ecosystem recovery given the decreases in emissions and acidic deposition over the past 30 years. Use this information to make predictions about ecosystem function going forward under alternative deposition scenarios and describe possible ecosystem recovery goals..
- Gain a better understanding of the effects of soil nitrogen de-saturation on ecosystems to aid in understanding changes that can be expected from forest ecosystems. Current ecosystem models suffer from a lack of resolution in soil nitrogen pools, but this effort may be aided by data derived from past and ongoing nitrogen fertilization studies.
- Monitor species compositional changes/trends to better understand the cause and effect relationship of these changes. Biogeochemical changes may be occurring because of loss of biodiversity, or declines in biodiversity may be a result of changes in biogeochemistry.
- Better define the relationship between DOC and ecosystem response to acidification and recovery. This relationship may also have implications for mercury methylation.

6.3 Relevance to Other Research in the Region and the Nation

The need for terrestrial research on field data to link soil acid-base chemistry with aquatic and forest response indicators is becoming more widely recognized. National Park Service and Forest Service in Shenandoah National Park, Virginia, and on Forest Service lands in West Virginia, North Carolina, Tennessee, and South Carolina are supporting model-based assessments of ecosystem response to changing levels of sulfur and nitrogen deposition. Many EMEP-supported projects also include biogeochemical connections of soils to surface waters.

7 Acidic Deposition Critical Loads Assessments and Other Modeling

Research aimed at evaluating the effectiveness of emissions reductions often stops short of determining whether the targeted reductions allow ecosystems to recover. Critical loads research estimates an exposure to one or more pollutants, below which significant harmful effects on specified sensitive elements of the environment do not occur. Critical loads can provide a means to look at ecosystem recovery depending on the definition of significant harmful effects and whether further emission reductions may be needed to promote full recovery. Ecosystem recovery can be broadly defined as a return of key ecosystem processes and variables to pre-acidification conditions. Important parameters to assess may include acid-neutralizing capacity of surface waters, base saturation of soils, and the degree of re-establishment of key biotic components and their respective functions. Chemical measures serve as indices that reflect the suitability of habitat for sensitive biota. Biogeochemical models such as MAGIC and PnET-BGC are available to predict and evaluate ecosystem responses to historical changes and future scenarios of atmospheric deposition. These models can also be used to look at over what time scale ecosystems may recovery; however, there is limited information on whether currently observable trends in some of these variables are likely to persist and whether and at what chemical condition biological components will likely respond.

A number of EMEP supported projects have contributed to the national, regional, and local critical loads assessments including ALTM, AEAP, and stream and soil surveys. EMEP funded two projects to model critical loads. One project (contract 10658) was developed to calculate the critical loads of sulfur and nitrogen that will result in aluminum mobilization. This project also compared and evaluated three approaches for estimating future acid-base chemistry conditions and the critical load of sulfur and/or nitrogen needed to avoid future stream acidification in the Adirondack region of New York: the empirical critical load; the dynamic time needed to research the critical load; and scenario modeling. The results of this comparison are being used in the second project, “Critical Loads of Sulfur and Nitrogen” (contract 10657), to protect and restore acid sensitive resources in the Adirondacks.

EMEP’s terrestrial critical load project (contract 10657) has shown that computer models (MAGIC) that identify target deposition loads are extremely sensitive to soil percent base saturation. This research has identified a need to better understand the role of percent base saturation where sensitive plant species are adversely affected.

7.1 Research Focus Going Forward

- Establish steady-state aquatic and terrestrial critical loads for sulfur and nitrogen deposition that defines significant harmful effects that promote recovery in ecosystems. Conduct additional research and monitoring to improve the current models that predict ecosystem changes with depositional changes. Improvements may include refinement of specific model parameters as well as the possible addition of new formulations.
- Conduct additional research and monitoring to improve the models on tree species composition and net forest productivity in order to understand critical loads for forests. For example, calciphilic species such as sugar maple and red spruce do not respond well to spring frost events and can be expected to be adversely affected by a changing climate.
- Monitor forest composition trends as changes may correlate with changes in surface water temperature, pH, TMDLs, net forest productivity, base saturation percent, or forest dynamics etc. With warming winters, it is anticipated that new forest species will begin to colonize New York State forests, changing competition for native species.
- Support studies to better understand the percent base saturation where sensitive vegetation is adversely impacted. Research on terrestrial critical loads has shown that the models used for identifying target loads are extremely sensitive to soil percent base saturation. For example, a base saturation of 12% seems to be an important threshold for Sugar Maples. More work is needed to relate base saturation to the health of various tree species.
- Conduct mapping based on some combination of existing information coupled with any required new information, and modeled projections. Map impacted areas across the State according to ecosystem sensitivity (proximity to critical loads) to identify watersheds that are, or that are projected to be, at risk and sensitive biota within those watersheds to help prioritize recovery efforts.

7.2 Relevance to Other Research in the Region and the Nation

In 2010, NADP formed the Critical Loads of Atmospheric Deposition Science Committee (CLAD). CLAD provides a national platform to discuss current and emerging issues regarding the science and use of critical loads for effects of atmospheric deposition on ecosystems in the United States. Most researchers engaged in critical load research work with CLAD to disseminate findings and to discuss approaches. In this way, CLAD facilitates technical information sharing on critical loads topics within a broad multi-agency/entity audience, fills gaps in critical loads development nationally, provides consistency in development and use of critical loads nationally, promotes understanding of critical loads approaches through development of outreach and communications materials.

There are also ongoing efforts to conduct total maximum daily load (TMDL) analyses for specific New York water bodies as required by the Clean Water Act. Critical load models are proving useful in developing TMDLs. Coordination of ongoing critical load and TMDL efforts will be beneficial.

8 Mercury Biogeochemical Processes

Scientists are making progress in understanding the biogeochemical processes driving the methylation of mercury in freshwater systems. This includes correlations with sulfur, anoxic conditions, DOC, acidic environments and other factors. Despite the importance of wetlands in mercury methylation biogeochemistry, relatively little work has focused on these systems. EMEP is assessing methylmercury bioaccumulation in the Hudson River based on DOC (contract 16297). Similarly, another EMEP project (contract 10661) is assessing the effects of climate and weather on mercury methylation and mercury flux from upland watersheds. While at least one model (MERGANSER) has been developed to predict mercury in freshwater piscivores, it has not been applied to New York waters.

More coastal or marine research is needed to advance the understanding of mercury methylation and how confounding factors, such as climate change or nutrients, will affect bioaccumulation in fin fish, shell fish, and other seafood. Additionally, given the vast amount of legacy mercury in marine systems, *in situ* mitigation efforts to constrain mercury methylation could be an important management tool going forward.

8.1 Research Focus Going Forward

- Conduct more research on the mercury methylation process and its relationship to DOC availability in different environments, including wetlands, lakes, streams, estuaries, and coastal areas. The methylation processes may vary at these diverse locations, given the different profiles in organic matter availability and other variables.
- Continue studying the relationship between nitrogen and mercury bioaccumulation in these systems. Recent research suggests that anthropogenic nitrogen loading and methylmercury bioaccumulation in fish are inversely related in estuarine systems.
- Research whether biodiversity changes can be expected to result in changes of commonly assumed mercury bioaccumulation rates up the food chain. Biodiversity changes in plants and/or animals may be affecting mercury bioaccumulation in wildlife.
- Conduct research, monitor, and synthesize data to better understand how increasing/decreasing nitrogen or sulfur deposition (acidification) will affect mercury methylation and bioaccumulation in terrestrial and aquatic ecosystems. Additionally, research the relationship between mercury deposition in terrestrial ecosystems and its subsequent impact on aquatic ecosystems.
- Develop models (e.g., MERGANSER) that can predict methylation and bioaccumulation of mercury in lakes, reservoirs, estuaries, and near-shore marine environments to support fish consumption advisories.

8.2 Relevance to Other Research in the Region and the Nation

These process-level research recommendations represent an important step in advancing knowledge concerning the biogeochemical cycling of mercury and methylmercury in lakes, streams, wetlands, terrestrial systems and coastal waters; the linkages to nutrient inputs and eutrophication; the connections to atmospheric mercury deposition and cycling of legacy mercury; the influence of climate on mercury retention within the watershed; and the bioaccumulation of methylmercury in marine biota, including those consumed by humans.

Such mechanistically focused studies will not only benefit the State, but they will also add and complement efforts in selected coastal regions of the United States (e.g., C-MERC). This information will be especially useful in developing/improving models for the behavior and fate of mercury and provide substantial value to local and federal public health and environmental agencies that issue human health advisories for commercial and sport fish consumption.

9 Effect of Multiple Stressors on Aquatic and Terrestrial Ecosystems and Biota

Changes in deposition are occurring at the same time as other large-scale influences on ecosystems. Climate change will undoubtedly cause changes in key processes as well as shifts in biological communities. Analyses of the interaction between climate change and the influences of atmospheric deposition will be critical for making long-term predictions of ecosystem health. Other factors, including changes in land use, species invasions/introductions, and extinctions will alter biological communities and the rates of key processes such as decomposition and nutrient cycling. There is also a lack of specific ecological endpoints (chemical and biological) for the array of aquatic and terrestrial ecosystems/communities in the New York State Forest Preserve, which are necessary in determining the loading standards being sought.

Research on surface-water chemistry shows that surface waters in a large number of New York lakes are slowly improving as a result of decreased acidic deposition rates; however, time-series analyses of water chemistry suggest that the rates of improvement exhibited at these lakes have slowed. Various biological communities have decreased in extent, persistence, and composition over the past few decades. Wildlife populations have also changed. Migrating songbirds and amphibians have declined, yet the major causes of these changes are not well established. The breadth and depth of widespread fish recovery is not well known; while fish species richness is no longer widely declining, species richness is not showing widespread recovery.

Scientists recognize that mercury affects aquatic food webs. Surveys have shown elevated mercury levels in terrestrial food webs as well, which have the potential to biomagnify methylmercury at higher rates than aquatic food webs. Once mercury is deposited on ecosystems, there is very limited information to assess how it may be transformed and transported by various processes. Songbirds (e.g., gleaners, red-winged blackbirds, tree sparrows) and other insectivore species are likely to continue to be affected, even after emissions are reduced.

EMEP studies have specifically evaluated a number of these research focus questions such as lake ANC/pH correlations with mercury bioaccumulation (contract 7608), weathering rates of calcium in soils to aid in soil recovery (contract 8649), mercury bioaccumulation in relation to DOC (contract 16297), and the effects of climate and weather on sulfur, nitrogen, and mercury flux (contract 10661). A project on eastern Long Island is looking at acidification of the Pine Barrens and how that acidification may be influencing mercury bioaccumulation (contracts 25929 and 28431). Similarly, an assessment of mercury in saltmarsh sparrows showed that in addition to habitat loss, partially due to climate change, mercury in these organisms may be playing a role in their decline (contracts 19881 and 22258). Many other projects have also helped address multiple stressor issues, but those projects have approached questions relating to multiple stressors in a less direct way. Ecosystems research projects contribute to the scientific knowledge of multiple stressors by touching on individual stressors and receptors or biogeochemical interactions in soils and aquatic and marine systems.

9.1 Research Focus Going Forward

- Research the interaction of SO_2, NO_x, NH_x, ozone, and mercury and how policy changes may result in unintended consequences or co-benefits. Multi-pollutant interactions, including reactions among these pollutants and their commensurate ecosystem impacts are not well known.
- Conduct research to better understand how climate change will affect acidification, recovery, and mercury effects by determining how native tree/plant species will respond to changing environmental conditions and the resultant effects on ecosystem structure and function. Geochemistry and soil processes are linked with tree/plant species composition.
- Monitor invasive plant/insect species composition and distribution in relation to nitrogen fertilization and climate to more closely to evaluate the impact they are having on biogeochemical processes, other species, and ecosystems.
- Research how the biogeochemistry of mercury, acidification, and soil recovery may be affected by changing hydrological factors. Precipitation is projected to increase in New York State coupled with periods with more severe droughts. Snowpack duration and depth is also expected to generally decrease.
- Evaluate the overall population size and health of certain key species or groups of species to determine and track the health of different ecosystems or use them experimentally to see how different recovery efforts and tests accelerate, decelerate, or do not affect the recovery process. Key plants and animals can serve as representatives of the health of ecosystems.

9.2 Relevance to Other Research in the Region and the Nation

With global climatic change, invasive species, continued acidic and mercury deposition, and other stressors many ecosystems, and the biodiversity they support, are undergoing major changes from anthropogenic stress. The Millennium Ecosystem Assessment details the issues that ecosystems are facing on a global level. Understanding how these rapid environmental changes are going to impact the function and services of ecosystems will be critical for understanding the extent of human impacts and for identifying the possible steps that can be employed to mitigate those impacts. While many studies look at the effects of individual stressors and how they affect natural systems, few studies have considered their combined or cumulative effects. In New York, the report "Responding to Climate Change in New York State"[5] explores multiple stressors that could be alleviated to ease ecosystem stress to climate change.

[5] http://www.nyserda.ny.gov/climaid

10 Ecosystem Management

As the levels of acidic and mercury deposition have declined, some watersheds in the State have begun to show signs of recovery. At the same time, many other watersheds and water bodies, particularly those with poor buffering capacity, may never recover without further intervention. Through the use of several ecosystem management options (e.g., watershed/in-stream liming, restoration of lake/stream ecosystem resilience through stocking of native fishes), scientists and resource managers may be able to accelerate ecological recovery. Some liming projects have taken place in the northeast region over the past 20 to 30 years, including the Adirondack Lake Acidification Mitigation Project, Living Lakes Project, Woods Lake investigations, and New York State Department of Environmental Conservation Lake Liming Program. Additionally, a multi-institutional collaborative effort has begun on a new in-stream and watershed liming project at Honnedaga Lake. Many ALTM lakes were part of these intensive investigations, either as limed lakes or control lakes, but limited information is available to guide resource managers in selecting cost-effective restoration projects that are most likely to succeed both in the short- and long-term. Policy makers and resource managers tasked with protecting and restoring impaired ecosystems need a better understanding of management options, costs, benefits, and application procedures.

10.1 Accelerated Recovery

Today’s Adirondack and Catskill soil databases do not necessarily constitute an adequate baseline (e.g. spatial representation, elevation, types of data) for terrestrial and aquatic resource recovery tracking. Also, managers of ecological resources need more information to guide them on which restoration projects best promote the recovery of biota. While scientists have conducted several major liming/mitigation studies over the past few decades, the costs, benefits and long-term impacts of these projects have not been well documented or developed to serve as useful resource management tools.

EMEP continues to conduct research into accelerated recovery processes. An ongoing project with USGS is looking at sugar maple health and growth rates in relation to calcium availability. Another project (contract PO9955) is comparing the previously limed Woods Lake watershed with control watersheds to assess the interactions among carbon, nitrogen, and calcium on the forest floor and within soils. Another project (contract 16299) is assessing how liming of watersheds (Woods Lake and Hubbard Brook, NH) have altered soil and stream chemistry over the long term. Until recently, no in-stream liming had taken place in New York State, but with the Honnedaga Lake Watershed Liming project (contracts 22237 and 27329), researchers can now compare the ecological effects of watershed and in-stream liming on aquatic and terrestrial systems. Additionally, this project also affords an opportunity to assess the effects of watershed liming on mercury mobilization and recovery of heritage strain brook trout.

Long-term monitoring of the lake biota (contract 16298) has shown changes in zooplankton and phytoplankton communities, and work by ALSC (contract 4915) has shown changes in the population numbers and species of fish in relation to increases in pH and ANC; however, researchers still do not fully understand what a “recovered” assemblage of biota would look like given the myriad of other ecological changes that have been concomitantly taking place, making the definition of a “recovered” ecosystem difficult to define.

10.2 Research Focus Going Forward

- Conduct experiments and demonstrations for accelerated recovery of terrestrial and aquatic ecosystems and organisms. Do not limit projects to soil restoration. Expand restoration efforts to other ecosystem compartments such as forests, wetlands, fish, plants, and other biota.
- Evaluate the definition of the characteristics of “restored” ecosystems in the Adirondack and Catskill mountains, given that many watersheds in these regions have been irreversibly changed by acidification, mercury deposition, invasive species, etc., It is likely that each region, watershed, water body etc. may require a different definition. Describe what the measureable metrics that could be used to evaluate the level of restoration of these systems and develop an index of recovery using these metrics.
- Investigate how the application of lime to streams and watersheds influences mercury mobilization and bioaccumulation in aquatic and terrestrial organisms.
- Assess past research on lake and watershed liming projects and interpret results relative to what is known. Evaluate and synthesize past efforts to reintroduce fish or other species in restoration efforts to inform future accelerated recovery activities. Compile and evaluate the relative cost-effectiveness of liming and other restoration efforts toward achieving management goals in variable ecological conditions. Reexamination of past efforts and previously collected data can elicit new ideas and opportunities.
- Evaluate technologies for use in surveying lakes and streams for fish. In the systems that have fish, amplify recovery and stocking efforts to try and restore fish populations. Hydroacoustic devices have been successful in locating fish in deep waters of lakes that were previously thought to be fishless. Similarly, a new approach to using environmental DNA shows promise as an inexpensive method to determine presence or absence of particular species in aquatic systems.

10.3 Relevance to Other Research in the Region and the Nation

Some liming projects have taken place in the northeast region over the past 20-30 years, including the Adirondack Lake Acidification Mitigation Project, Living Lakes Project, Woods Lake investigations, and New York State Department of Environmental Conservation Lake Liming program. Additionally, work has begun on a new in-stream and watershed liming project at Honnedaga Lake. A number of ALTM lakes were part of these intensive investigations, either as limed lakes or control lakes, but limited information is available to guide resource managers in selecting cost-effective restoration projects that are most likely to succeed both in the short- and long-term. A better understanding of management options, costs, benefits, and applications would be useful to policy makers and resource managers tasked with protecting and restoring impaired ecosystems.

11 Economic Assessments

Environmental policies and regulations that reinforce the connections between the wellbeing of humans and the environment often find support from a wide range of stakeholders. Information about the links between the natural and social sciences is weak in some areas. This weakness undermines efforts to perform social or economic valuation of ecosystems or to evaluate environmental changes in terms of cost-benefit analysis. When ecosystem services provided by healthy natural systems are not accounted for in terms of benefits to humans, a substantial portion of the benefits of environmental regulations remain outside of this cost-benefit calculation. Further, the issue of discounting is critical to cost-benefit analysis in relation to issues of fairness and ethics in the choice of a discount rate. Research to improve the understanding of how mercury pollution and the acidification of ecosystems affects ecosystem services (e.g., provisioning, regulating, supporting or cultural services), and thereby New York State's economy, would aid in a better appreciation and more comprehensive understanding of the benefits resulting from emissions regulations and other policies.

11.1 Ecosystem Economic Valuation

The benefits of the regulation of environmental pollutants such as SO_x, NO_x, NH_x and mercury are increasingly being weighed against the potential negative economic impacts. The links between the natural and social sciences are weak in some areas, which undermines efforts to perform economic valuation of ecosystems or evaluate changes in benefit-cost analysis. A particular weakness for social science valuation is the lack of information and modeling (analogous to MAGIC or PnET) about how terrestrial ecosystems respond. Integrated scientific assessments can help build a crucial bridge between scientific findings and the social science community, especially in reference to valuation of resources. It also provides a method for identifying the value of additional information that can help inform research priorities over the chain of effects linking human activities and ecological impacts.

Meaningful economic analyses consider changes in ecological resources from a baseline to a changed condition. To help with economic valuations, it is important to relate scientific findings to endpoints and measures that people can understand, such as human health, recreation, and wildlife. Connections between EMEP-funded scientific research and the social sciences have been limited to the EMEP Outreach program. Additional efforts to provide some type of valuation of resources and the jobs that a restored ecosystem would support are essential for informing policy makers of the true costs and benefits of policy decisions. EMEP has not funded any research to address this need.

11.2 Research Focus Going Forward

- Collect and synthesize information to describe the different human uses of ecosystems (ecosystem services), their current amounts and values, and how such uses and values respond to changes in ecosystem quality related to acid and mercury deposition.
- Develop a baseline value, working with an aspect of ecosystem services (i.e., regulation, provisioning services) or a specific resource (e.g. timber, tourism) and changes relating to acidic and mercury deposition. Calculate how the current state of the environment compares and/or how changes going forward can be expected to compare to the baseline in terms of cost-benefit and/or overall value to New York State.
- Evaluate the limits to the quantification of costs and benefits and how non-quantifiable costs and benefits associated with acidification and mercury issues can be included in policy analysis.
- Make use of critical loads models to develop scenarios of how ecosystems services are affected by various deposition loads.

11.3 Relevance to Other Research in the Region and the Nation

When ecosystem services provided by healthy natural systems are not accounted for in terms of benefits to humans, a substantial portion of the benefits of environmental regulations remain outside of this cost-benefit calculation. In 2012, EPA’s National Center for Environmental Economics issued “Retrospective Study of the Costs of EPA Regulations: An Interim Report of Five Case Studies."[6] This report developed costs associated with EPA regulations but did not include the environmental benefits associated. Research to improve the understanding of how mercury pollution and the acidification of ecosystems affects ecosystem services (e.g., provisioning, regulating, supporting or cultural), and thereby New York State’s economy, would aid in a better appreciation and more comprehensive understanding of the benefits resulting from emissions regulations and other policies.

[6] http://yosemite.epa.gov/ee/epa/eed.nsf/pages/RetroCost.html/$file/retro-cost-3-30-12.pdf

Appendix A

NYSERDA Agreements Cited in the Environmental Research Program Plan –

Ecological Effects of Deposition of Sulfur, Nitrogen, and Mercury

Contract	Project Title	Entity	Project Completed
4915 and 4915A 25352 and 25552	Long-Term Monitoring Program for Evaluating Changes in Water Quality in Adirondack Lakes & Streams	Adirondack Lakes Survey Corp. and the US Geological Survey	2010, 2011, 2012 and ongoing
6818	Mercury Deposition Monitoring in the Catskills	US Geological Survey	2012
7608 and 27965	Long-term Monitoring and Assessment of Mercury Based on Integrated Sampling using the Common Loon, Prey Fish, Water, and Sediment	Wildlife Conservation Society and Biodiversity Research Institute	2009 and 2012
7612* and 7716	Strategic Monitoring of Mercury in New York State Fish	NYS Dept. Environmental Conservation and Adirondacks Lakes Survey Corp.	2008
7613, 7717, and 7718	Assessment of Chemistry and Benthic Communities in Streams of the Oswegatchie-Black River Basins	US Geological Survey, Adirondack Lakes Survey Corp. and University of Texas at Arlington	2008
8646	Assessment of Nitrogen and Acidic Deposition Impacts to Terrestrial and Aquatic Ecosystems of Tug Hill	SUNY College of Environmental Science and Forestry	2011
8649	Assessing the Sensitivity of New York Forests to Cation Depletion	SUNY College of Environmental Science and Forestry	2009
10657	Critical Loads of Sulfur & Nitrogen Deposition to Protect & Restore Acid-Sensitive Resources in the Adirondacks	E&S Environmental Chemistry	Ongoing
10658 and 10658A	Empirical Estimation of the Critical Load for Inorganic Aluminum Mobilization in the Western Adirondacks	Cary Institute and E&S Environmental Chemistry	2011

Appendix A continued

Contract	Project Title	Entity	Project Completed
10659	Land Atmosphere Dynamics of Mercury & Ecological Implications for Adirondack Forest Ecosystems	Syracuse University	Ongoing
10660	Acid Deposition Effects on Adirondack Ecosystems: Linkages Among Streams, Soils, & Sugar Maple Health	E&S Environmental Chemistry and US Geological Survey	Ongoing
10661	Evaluation & Protection of Adirondack Ecosystems: Impacts of Acid & Mercury Deposition on Watersheds	SUNY College of Environmental Science and Forestry	2013
10662	Deacidification: Dissolved Organic Carbon & Nitrate Export--Identifying Connections	Cornell University	Ongoing
16295	East Central Adirondack Stream Survey	US Geological Survey, Adirondack Lakes Survey Corp. and University of Texas at Arlington	Ongoing
16296	Methylmercury Bioaccumulation within Montane, Terrestrial Food webs in the Adirondack Park of New York State	Syracuse University	Ongoing
16297	Geographic Variation of Methylmercury Bioaccumulation in the Hudson	SUNY Stony Brook	Ongoing
16298	Chemical & Biological Monitoring of Adirondack Lakes to Examine Ecosystem Impacts & Recovery from S & N Deposition to inform Policy	Rensselaer Polytechnic Institute	Ongoing
16299	Response of Acidified Soils and Associated Surface Waters to Reduced Atmospheric Acid Inputs and Calcium Mitigation Strategies	Syracuse University	Ongoing
16300	Acid Deposition and Mercury Research Synthesis	E&S Environmental Chemistry and Syracuse University	Ongoing

Appendix A continued

Contract	Project Title	Entity	Project Completed
19881	Mercury Assessment of Saltmarsh Sparrows in Long Island, NY	Biodiversity Research Institute	2011
21309	Environmental R&D: Outreach and Writing	Eastern Research Group, Inc.	Ongoing
22237	Experimental In-Stream Liming to Restore Spawning and Young-of-Year Habitat for Heritage Strain Brook Trout in Honnedaga Lake	US Geological Survey	Ongoing
22258	Mercury Assessment of Saltmarsh Sparrows in Long Island, NY; Phase II	Biodiversity Research Institute	2012
22951	LTM Evaluation Fellowship	SUNY College of Environmental Science and Forestry	2012
24012	AMNet at Rochester (NY43)	NYS Dept. Environmental Conservation, NADP, Great Lakes Commission	2013
25929	A Survey of Mercury Effects on Wildlife of Suffolk County Pine Barrens and Coastal Ponds	Biodiversity Research Institute and the Nature Conservancy	Ongoing
26578 and 30460	AMNet at Huntington Forest (NY20)	Clarkson University	Ongoing
27329	The Effects of Watershed and In-Stream Liming on Mercury in Surface Waters and Biota of Honnedaga Lake	US Geological Survey	Ongoing
28431	Effects of acid rain on the ecological health of Long Island's forests and ponds in the Central Pine Barrens and TNC's Mashomack Preserve.	US Geological Survey and the Nature Conservancy	Ongoing

Appendix A continued

Contract	Project Title	Entity	Project Completed
30388	Songbirds as Indicators of Major Source Types of Mercury for New York Ecosystems	Biodiversity Research Institute	Ongoing
31250	Monitoring of an Adirondack Ecosystems: Impacts of Acidic and Mercury Deposition and Climate Change on Watersheds	SUNY College of Environmental Science and Forestry	Ongoing
PO9955	Investigating Interactions Between Carbon, Nitrogen, & Calcium in the Adirondack Forest (EMEP Fellowship)	Cornell University	Ongoing
PO9956	The Production & Transfer of Methylmercury Within Terrestrial Food webs Across the Northeastern Lands (EMEP Fellowship)	Syracuse University	Ongoing

Completed project reports available at: http://www.nyserda.ny.gov/en/Publications/Research-and-Development/Environmental/EMEP-Publications/EMEP-Final-Reports.aspx

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NYSERDA Environmental Research Program Plan

Research Area 1: Ecological Effects of Deposition of Sulfur, Nitrogen, and Mercury

October 2013

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
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