

MercNet—Establishing a Comprehensive National Mercury Monitoring Network



2008
WORKSHOP
REPORT

Acknowledgements

Workshop organized by the U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, National Park Service, Cherokee Nation, Florida Department of Environmental Protection, Minnesota Pollution Control Agency, BioDiversity Research Institute, National Atmospheric Deposition Program, Syracuse University, and University of Connecticut.

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Executive Summary

Methylmercury levels in fish and other biota routinely exceed thresholds considered potentially harmful to people and fish-eating wildlife throughout much of the United States. Mercury emitted to the atmosphere by industrial activities (e.g. coal-fired power generation, chlorine production) deposits to watersheds, transforms into highly bioavailable methylmercury, and magnifies to high concentrations in food webs. Growing awareness of changing mercury levels in the environment has sparked widespread concern about ecological and human health effects.

Federal agencies, states, and tribes—in partnership with academic researchers, non-governmental organizations, and industry—have been actively engaged in understanding and developing solutions to the mercury pollution problem. Developing regulatory policies designed to reduce mercury emissions from stationary sources, including coal-fired power plants, is one of the primary ways states and the federal government are addressing the mercury threat.

Sufficient information is not currently available for many areas of the United States to fully and accurately assess the

Policymakers, resource managers, and the public have many questions about mercury in the environment. For example:

- How are mercury emissions and deposition to the environment changing as a result of implemented policies and programs?
- How are ecosystems responding to changes in mercury pollution?
- What reductions in mercury emissions are needed before fish can be eaten safely?
- How will other factors such as land management, climate change, and acidic deposition influence the behavior of mercury in the environment and its accumulation in food webs?

We can answer some of these questions, in some places, but current resources cannot address these critical environmental policy questions on national and regional scales. Our existing monitoring infrastructure needs to be linked into a comprehensive, multimedia network with coverage in all regions of the country.



Photo credit: Daniel Poleschook, Jr., and Ginger Gumm

benefits and effectiveness of mercury reduction measures. Policymakers, scientists, and the public need a national monitoring program to accurately quantify regional and national changes in atmospheric deposition, ecosystem contamination, and bioaccumulation of mercury in fish and wildlife in response to changing mercury emissions. In the absence of a national mercury monitoring program, federal, state, and tribal agencies and other organizations are collaborating to understand mercury in the environment using limited existing data and monitoring capabilities. This report is the result of a multi-stakeholder, national mercury monitoring workshop, held May 5–7, 2008, to envision a comprehensive and integrated national mercury monitoring network. The report highlights strategies and partnerships for the design and implementation of a national network for tracking mercury pollution in ecosystems.

The process by which mercury deposits to watersheds, transforms to methylmercury, and magnifies to high concentrations in food webs is complex, requiring monitoring of all components of the mercury cycle to assess how changing emissions and deposition affect fish, wildlife, and people. Federal, state, and tribal agencies and other institutions operate a number of programs that monitor how mercury enters, cycles, and impacts ecosystems. However, all parts of the mercury cycle are not monitored, leaving major data gaps nationwide. In addition, agency mercury monitoring and research programs, developed and implemented for a variety of reasons, often sample over different spatial scales and time periods using disparate data-gathering protocols. Consequently, this presents a challenge to effectively combine resulting datasets to provide a complete national view of mercury in the environment.



Agreement emerged from the May 2008 workshop regarding mercury monitoring network goals, objectives, and major design elements. Workshop participants also came to agreement about how to focus collaborative efforts in the near term. Refinement of the monitoring network design will emphasize creation of a national framework for site selection and data sharing. Network planners will seek opportunities to leverage existing monitoring activities and funding sources through engagement with the broader mercury community. Outreach and support-building for existing and expanded monitoring will be directed toward policymakers and federal and state agencies.

In May 2008, scientists, policy analysts, and natural resource managers representing academia, federal and state agencies, tribes, industry, and non-governmental organizations met in Annapolis, Maryland, to refine the scientific and technical design of a standardized, national mercury monitoring network; explore potential implementation strategies; and share information on existing North American mercury monitoring and research programs. The workshop was an important step in building broad support around a

conceptual design for MercNet—a comprehensive and integrated monitoring network for the United States. Workshop participants agreed that the network would require standardized, multimedia sampling (i.e., air, water, sediments, fish, and wildlife) through national distribution of approximately 20 intensive monitoring sites, each accompanied by about 10 to 20 cluster sites. The network would operate for an extended period (10–40 years) to quantify the range of responses expected among the nation's diverse ecosystems.

A national mercury monitoring network must serve a wide range of constituencies and meet multiple objectives. In recent years, extensive planning by a broad-based consortium of scientists, resource managers, and policy analysts has created a foundation for MercNet. The network envisioned will facilitate collaboration among diverse programs and agencies to produce comprehensive, nationally consistent, long-term mercury data through a cost-effective approach. At this time, new funding mechanisms do not exist for expanded mercury monitoring. Thus, efforts to establish the network must leverage existing monitoring capabilities and infrastructure, while striving toward a robust and coordinated set of monitoring sites that will provide the full range of information needed. Should new funding become available, implementation of the monitoring infrastructure described in this report would provide the nationally consistent monitoring necessary for tracking changing mercury levels and understanding ecological effects and response.



National Mercury Monitoring Workshop Steering Committee

- Richard Artz, National Oceanic and Atmospheric Administration
- Thomas Atkeson, Florida Department of Environmental Protection
- Ryan Callison, Cherokee Nation
- Charles Driscoll, Syracuse University
- David Evers, BioDiversity Research Institute
- David Gay, National Atmospheric Deposition Program
- Richard Haeuber, U.S. Environmental Protection Agency
- David Krabbenhoft, U.S. Geological Survey
- Robert Mason, University of Connecticut
- Gregory Masson, U.S. Fish and Wildlife Service
- Kristi Morris, National Park Service
- David Schmeltz, U.S. Environmental Protection Agency
- Edward Swain, Minnesota Pollution Control Agency



Introduction

Researchers, natural resource managers, and policymakers working to address the mercury problem recognize the need for an integrated national mercury monitoring network to regularly provide accurate, standardized information about ambient concentrations, deposition, watershed cycling, bioaccumulation, and biological effects of mercury.

I. Benefits of a national monitoring network

Why do we need enhanced mercury monitoring?

Human and wildlife exposure to mercury has increased, primarily through eating mercury-contaminated fish. Mercury is a naturally occurring element, yet industrial activities, such as fossil fuel combustion and waste incineration, release mercury to the atmosphere where it can be transported locally, regionally, and globally. Mercury in the atmosphere deposits to the Earth's surface primarily in inorganic forms.

Within watersheds and lakes, natural processes convert inorganic mercury to a highly bioavailable and toxic organic form—methylmercury—that is readily magnified to high concentrations in the food web (see figure 1). Exposure to toxic levels of mercury largely occurs through consumption of organisms with elevated methylmercury. Adverse effects on reproduction and neurological function have been observed in humans and wildlife with elevated levels of methylmercury.

Growing awareness of changes in mercury in the environment—in atmospheric transport and deposition, terrestrial and aquatic ecosystems, and aquatic food webs and wildlife—has sparked widespread concern about ecological and human health effects. Mercury concentrations in fish and other biota in the United States now routinely exceed thresholds considered potentially harmful, particularly to fish-eating humans and wildlife (see figure 2). Fish consumption advisories, including significant coastal advisories, have been issued throughout the nation in response to high levels of mercury in fish.

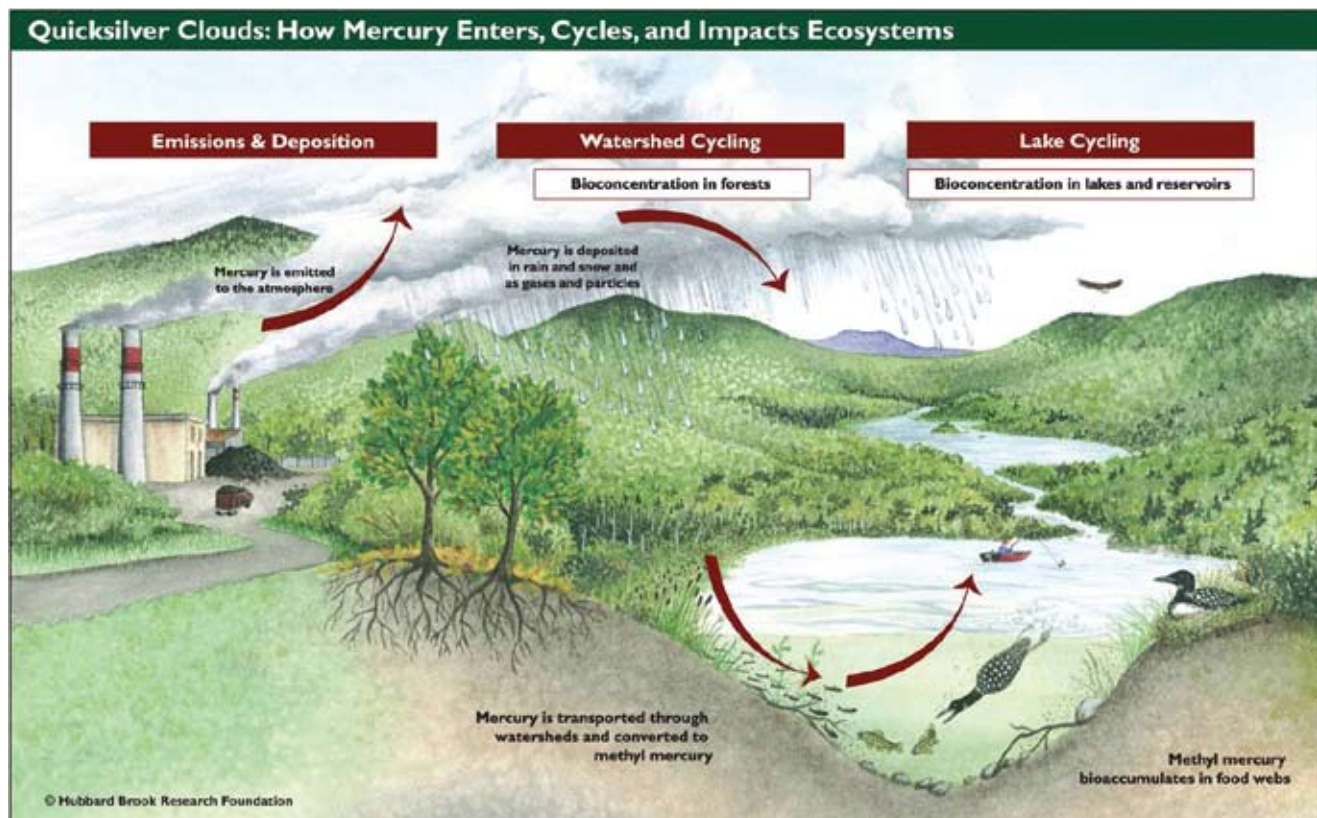


Figure 1. How mercury enters, cycles, and impacts ecosystems (from *Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States*, Hubbard Brook Research Foundation, 2007).



Introduction

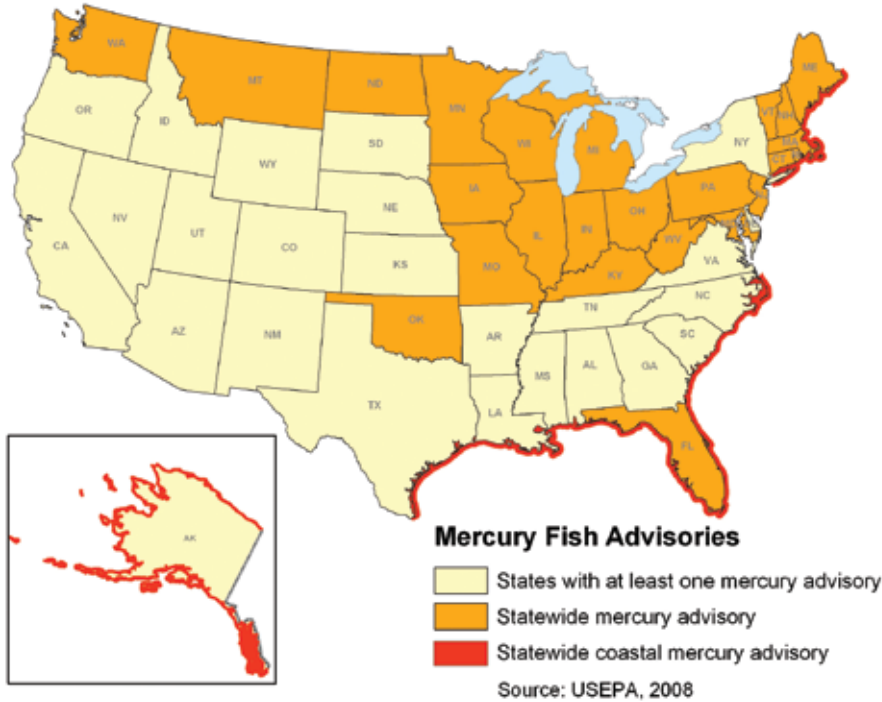


Figure 2. States with mercury-fish consumption advisories (EPA, 2008).

Methylmercury contamination has adversely affected the benefits derived from fishery resources in many of the nation's inland and coastal waters. In 2006, methylmercury was responsible for 80 percent, or 3,080, of the fish consumption advisories posted in the United States. In addition, 48 states, one territory, and two tribes had advisories attributed to mercury. The number of statewide fish consumption advisories issued for coastal waters, lakes, and rivers in the United States has increased substantially in the past two decades. In 2006, 23 states had mercury-related, statewide fish consumption advisories for lakes; 21 had statewide advisories for rivers, and 13 had statewide advisories for coastal waters. More than 57,400 km² of lake area and 1,420,000 km of rivers in the United States were under advisory for mercury in 2006. Based on more recent data from the National Fish and Wildlife Contamination Program, fish consumption advisories now blanket the entire nation, as shown on the map above.

Sources: 2005/2006 national listing of fish advisories. EPA, Fact Sheet EPA-823-F-07-003, Office of Water, Washington, DC. Available at www.epa.gov/waterscience/fish/advisories/2006/tech.pdf; USEPA National Fish and Wildlife Contamination Program, 2008.

Mercury is released to the environment in several ways, but the dominant pathway is airborne emissions and deposition. Coal-fired power plants are the largest single source of anthropogenic mercury in the United States, followed by industrial boilers and electric arc furnaces. Mercury emissions from some sources have decreased substantially since passage of the 1990 Clean Air Act Amendments. However, emissions from coal-fired power plants remain largely unchanged. Developing regulatory policies designed to reduce mercury emissions from coal-fired power plants and other sources is one of the primary ways states and the federal government are addressing the mercury problem. Sufficient information is not currently available for many areas of the country to fully and accurately assess the benefits and effectiveness of these mercury reduction measures. Policymakers, scientists, and the public need a comprehensive and integrated mercury monitoring network to accurately quantify regional and national

changes in atmospheric deposition, ecosystem contamination, and bioaccumulation of mercury in fish and wildlife in response to changing mercury emissions.

Who needs mercury monitoring data and why?

As mercury regulations are implemented, a wide range of constituencies need information about mercury in the environment. It is clear that a mercury monitoring network must serve multiple objectives given the types of information needed by federal agencies, states, tribes, academic researchers, non-governmental organizations, the private sector, and the public.

Informing federal and state mercury policy. The desired outcome of mercury emission reduction policies and programs is reduced mercury risks to humans and wildlife. Critical information is needed to understand and quantify the linkages between mercury emissions, ecosystem response,

“Where will we get the biggest bang for our buck? It may be domestic, regional, or international sources. The network is necessary to tell policymakers how well programs are working and where to go next. Getting that information systematically from the network will be a real challenge.”

Samuel Napolitano
U.S. Environmental Protection Agency



and human health concerns. Since consumption of fish is the primary exposure pathway in humans, a primary focus of the scientific effort has been on mercury contamination of aquatic food webs. Consumption of fish is also an important pathway of methylmercury exposure for wildlife at the top of the food webs. Additional monitoring information is needed to help determine whether observed changes in mercury concentrations in fish and other biota are related to regulatory controls on mercury emissions.

Providing data for the development and refinement of predictive models. Producing answers to policy and management questions about the sources and effects of mercury emissions requires the development and application of computer models. Advancing understanding of atmospheric transport, deposition, and ecological transformation of mercury requires spatially and temporally rich monitoring data. High-resolution atmospheric mercury data are needed to improve atmospheric model estimates of wet, dry, and total mercury deposition, and to assess source-receptor relationships. Models can help in understanding the spatial and temporal variability of mercury in the atmosphere, although local, regional, and international sources and variable forms of mercury in the atmosphere greatly complicate this task. Ecological models combine mercury deposition data with indicators of ecosystem sensitivity, such as high capacity for mercury methylation, and help in understanding bioaccumulation of mercury in fish and other biota.

Characterizing biological effects of mercury exposure. To implement and assess conservation strategies, resource managers need information about mercury exposure and resulting adverse effects on biological organisms, species, and communities. While there has been significant work to understand mercury transfer through ecological systems and food webs, expanded datasets are needed to understand the relationship between changing mercury concentrations and biological effects. Measurements of environmental mercury that are comparable over time and location are particularly important.

“It is important to ensure that the detection of mercury can be tangibly tied to environmental effects. Congress wants to know whether the presence of a pollutant in the environment translates into effects in the environment. FWS is interested in monitoring mercury trend data because they will affect our management actions and improve prevention and restoration activities.”

**Tiffany Parsons
U.S. Fish and Wildlife Service**

What is the context for a national mercury monitoring network?

The regulatory context for mercury emissions is changing. Federal agencies, states, and tribes are developing plans and policies for reducing mercury emissions from stationary sources and will continue to pursue important partnerships in this effort. Under any regulatory scenario, there is a clear need for a monitoring network that can accurately evaluate the impact of changing mercury emissions on the environment. For example, implementation of Total Maximum Daily Loads (TMDLs) by the states requires tracking and managing mercury levels in aquatic ecosystems. Similarly, development and implementation of federal and state mercury emission control regulations requires detailed data on mercury in the environment.

At this time, new funding mechanisms are not in place for expanding monitoring of ecological responses to mercury contamination. Given funding constraints, design of a mercury monitoring network will initially emphasize coordination across existing monitoring activities. Where possible, the network will leverage infrastructure that is already in place while striving towards a robust and coordinated set of sites that will meet the full range of monitoring objectives. Despite funding shortages and other challenges, the mercury research and monitoring community has successfully worked together on data-gathering and modeling to advance scientific understanding of this critical environmental and public health issue.

What has been done to develop a comprehensive, integrated mercury monitoring network?

Considerable progress already has been made in the design of a national mercury monitoring network. In 2003, more than 30 mercury specialists with expertise in atmospheric, terrestrial, and aquatic processes gathered in Pensacola, Florida for the North American Workshop on Mercury Monitoring and Assessment. This workshop, sponsored by the U.S. Environmental Protection Agency (USEPA) and the Electric Power Research Institute (EPRI) and convened by the Society of Environmental Toxicology and Chemistry (SETAC), proposed a framework for a national-scale program to monitor changes in mercury concentrations in the environment. Workshop participants recommended a set of environmental measurements and indicators to monitor trends in mercury concentrations in air, land, water, and biota to assess ecosystem responses to reductions in mercury emissions. They also recommended a general nested sampling design for the monitoring network that will enable integrated assessment of mercury in the environment on a national scale.



Introduction



USEPA/SETAC North American Workshop on Mercury Monitoring and Assessment, Pensacola, FL

Mason et al.
2005, *ES&T*
39:14A-22A

Comprehensive mercury monitoring bills introduced in House and Senate

2003 2004 2005 2006

A peer-reviewed journal article (2005)¹ and a subsequent book (2007)² published recommendations from this workshop.

Much more has been accomplished since 2003. New work, organized through the National Atmospheric Deposition Program (NADP) Atmospheric Mercury Initiative, facilitated collaboration among federal, state, and academic research and monitoring groups to provide high-resolution, high-quality data at 10 sites to estimate changes in atmospheric mercury concentrations and dry mercury deposition. In Congress the House and the Senate have put forth authorization bills that charge multiple federal agencies with establishing a national mercury monitoring program (H.R.1533 and S.843, respectively)³. In the Northeast, a team of scientists convened by the Hubbard Brook Research Foundation synthesized regional mercury data under a Northeastern Ecosystem Research Cooperative initiative, and modeled mercury emissions from local coal-fired power plants. This work generated important findings about the presence of biological mercury “hot spots” and implications of mercury deposition reductions for mercury levels in biota, and highlighted the need for an enhanced mercury monitoring program to assess the response to emissions reductions. This team produced a special issue of the peer-reviewed journal *Ecotoxicology* (Vol. 14, Issues 1–2, March 2005), two synthesis papers in the

peer-reviewed journal *BioScience*⁴, as well as *Mercury Matters*⁵, a report communicating these scientific findings to general audiences.

II. 2008 National Mercury Monitoring Workshop

Who was involved in the workshop?

In 2007, EPA’s Office of Atmospheric Programs organized a 13-person National Mercury Monitoring Workshop Steering Committee, with representatives from research and monitoring organizations and federal, state, and tribal agencies (see Appendix A for membership list). The purpose of the Steering Committee was to convene a workshop to explore options to design and implement a comprehensive, national mercury monitoring network. Since the mandate to monitor, assess, and report on mercury in the environment cuts across numerous federal, state, and tribal agencies, the steering committee recognized the need to expand coordination and agreement among a broad-based consortium of stakeholders about near- and medium-term monitoring needs for tracking mercury pollution in ecosystems.

1 Mason RP, Abbott ML, Bodaly RA, Bullock Jr. OR, Driscoll CT, Evers D, Lindberg SE, Murray M, Swain EB. 2005. *Monitoring the response of changing mercury deposition*. *Environ. Sci. Technol.* 39:14A-22A.
2 Harris R, Krabbenhoft DP, Mason R, Murray MW, Reash R, Saltman T. 2007. *Ecosystem responses to mercury contamination: indicators of change*. SETAC, Boca Raton, FL.
3 Full text of these bills is available from the Government Printing Office: H.R.1533 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&doid=fh1533ih.txt.pdf; and S.843 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&doid=fs843is.txt.pdf

4 Driscoll, C.T., Y.-J. Han, C.Y. Chen, D.C. Evers, K.F. Lambert, T.M. Holsen, N.C. Kamman, and R.K. Munson. 2007. *Mercury contamination in forest and freshwater ecosystems in the Northeastern United States*. *BioScience*. 57:17-28.
Evers, D.C., Y.-J. Han, C.T. Driscoll, N.C. Kamman, M.W. Goodale, K.F. Lambert, T.M. Holsen, C.Y. Chen, T.A. Clair, and T. Butler. 2007. *Biological Mercury Hotspots in the Northeastern United States and Southeastern Canada*. *BioScience*. 57(1):29-43.
5 Driscoll, C.T., D. Evers, K.F. Lambert, N. Kamman, T. Holsen, Y.-J. Han, C. Chen, W. Goodale, T. Butler, T. Clair, and R. Munson. *Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States*. Hubbard Brook Research Foundation. 2007. Science Links Publication. Vol. 1, no. 3.



Northeastern mercury scientists from the Hubbard Brook Research Foundation published two papers in *BioScience* on mercury in the environment. Both papers indicated the need for a comprehensive and integrated nationwide mercury monitoring program.

On May 5–7, 2008, the Steering Committee held a National Mercury Monitoring Workshop of approximately 50 participants in Annapolis, Maryland, to share mercury monitoring information, refine the scientific and technical basis for the design of a national mercury monitoring network, and explore potential implementation strategies.⁶ Participants represented diverse perspectives and disciplines, with specific types of mercury-related expertise and involvement in mercury monitoring, modeling, and research in academia, federal and state agencies, tribes, non-governmental organizations, and other sectors.⁶

What were the goals of the workshop?

The workshop focused on three goals:

- Distill recommendations from previous work on measurement parameters for tracking ecological responses to mercury;
- Share information and explore potential collaboration among existing North American sites and programs that monitor chemical and biological endpoints of mercury contamination (e.g., air, water, watershed, sediments, biota); and
- Identify mercury monitoring data gaps and explore options for eliminating those gaps.

The workshop focused on atmospheric, terrestrial, freshwater, and coastal ecosystems in the United States, although linkages to ecosystems and monitoring programs in Canada and Mexico were encouraged.

How was the workshop organized?

The workshop was organized around a set of key monitoring network design questions. For some of these questions, substantial progress already had been made, and workshop discussions focused on refinement of earlier work:

- I. What are the goals and objectives of a national mercury monitoring network?
- II. What are the major elements needed to meet network goals and objectives?

For other network design questions, robust preliminary work was used to inform discussion of major remaining issues.

- III. What monitoring capabilities are already in place?
- IV. What existing sites can meet monitoring objectives?
- V. How can we develop the network?

In the workshop, a range of panelists and presenters shared ideas and information about network goals, objectives, and major elements. In breakout groups and full group discussions, participants reflected on preliminary options presented by the Steering Committee for selection of monitoring sites. Participants helped to fill information gaps for existing and potential sites, in addition to exploring options for near-term strategies to develop the network.

⁶ See <http://nadp.sws.uiuc.edu/>.



Elements of a National Mercury Monitoring Network

Workshop participants reviewed goals, objectives, and proposed network design strategies, and emphasized the importance of national-scale coordination and comprehensive measurement of key ecosystem variables related to mercury pollution. To enable an integrated view of ecosystem responses to emission control policies, focus should be placed on systems expected to respond rapidly to changes in mercury deposition. There was broad agreement with proposed measurement parameters and a nested sampling strategy involving intensive and cluster sites.

Site selection should be focused on the ability to document trends and establish causal links between mercury emissions and ecosystem responses, and to provide useful input data for predictive atmospheric and watershed models.

Mercury cycling is complex. To quantitatively document the full range of ecosystem responses to changing mercury emissions, more robust monitoring of terrestrial, freshwater, estuarine, and coastal ecosystems—and greatly enhanced integration of data gathering—is needed.

To support national environmental policy development and assessment, it is essential that the monitoring network provide nationally consistent data that are comparable across ecosystems over time. Establishment of clearly defined site selection criteria and standardized measurement protocols—that are sufficiently flexible to allow the use of reliable, historical data to document trends—will be important to the success of the network. Scientific collaboration will require development of effective data management systems, accessible databases, and diverse reporting mechanisms. Finally, transparent processes for quality assurance are necessary to ensure scientific defensibility.

“The idea is to get everyone to operate the technologies in the same fashion.”

David Gay
National Atmospheric Deposition Program

I. Network goals and objectives

What is the overall goal of the mercury monitoring network?

Prior to the workshop, the Steering Committee proposed the following goal:

To establish an integrated, national network to systematically monitor, assess, and report on policy-relevant indicators of atmospheric mercury concentrations and deposition, and mercury levels in land, water, and biota in terrestrial, freshwater, and coastal ecosystems in response to changing mercury emissions over time.

Workshop discussions expanded on this statement to emphasize the importance of linking monitoring activities explicitly to the information needs of policymakers, resource managers, and researchers for managing risk and predicting outcomes.



Other key attributes of the desired monitoring network include national-scale coordination to enable an integrated view of changes in mercury associated with emission control policies. This will require comprehensive measurement of key variables and should include monitoring of ecosystems expected to be sensitive to changes in mercury deposition.

What are the main objectives of the mercury monitoring network?

The Steering Committee proposed monitoring network objectives. The workshop participants reviewed and revised the objectives to align with the full range of mercury information needs. The result was the following list:

1. *Establish baseline mercury concentrations in multiple ecosystem compartments* that document environmental conditions before implementation of new mercury emissions controls to detect temporal trends that might be attributable to these controls. This entails building on historical datasets and accounting for baseline conditions that vary in space and time.



2. *Track spatial patterns and long-term trends* in mercury concentrations in specific ecosystem compartments including airsheds and watersheds, aquatic ecosystems, aquatic biota, and wildlife as mercury emissions controls are implemented. This entails a comprehensive geographic approach that accounts for spatial variability, and a long-term, consistent set of measurements to assess temporal response.
3. Provide data to *assess linkages between atmospheric mercury emissions and methylmercury concentrations in biota*, and how these change over time. This entails quantifying relationships between mercury emission sources and aquatic receptors, and accounting for ecological 'lags' with particular attention to contamination of aquatic food webs and fish to provide information needed for health risk assessment and fish consumption advisories.
4. *Document trends in biological indicators of mercury exposure and effects* relative to changes in mercury loadings to ecosystems, including ecotoxicological effects on organisms and populations.
5. Provide mercury and ancillary data to *evaluate predictive and diagnostic models* and to *advance the development of mercury cycling models and models to assess source-receptor relationships*. This entails integration of monitoring and modeling activities to ensure that data can be efficiently used to build, test, and run models that account for the full range of factors affecting mercury abundance and methylation rates.
6. *Assess potential ecological harm* and linkages to air emission sources for sites and wildlife of conservation concern. This entails quantifying cause-and-effect relationships among mercury emissions, deposition, and wildlife exposure.
7. *Connect national mercury monitoring efforts to other monitoring programs* in North America and adjacent waters, where feasible, to maximize integration of expertise and monitoring capacity. Strive for effective interaction with mercury monitoring programs, both in North America and globally.

II. Mercury measurements

Major network design concepts were originally developed at the 2003 Pensacola workshop and subsequently published in Harris et al. (2007). Presentations provided by Robert Mason (University of Connecticut) and David Krabbenhoft (U.S. Geological Survey) summarized these concepts and were supplemented by workshop discussions.

What mercury parameters should be measured?

Monitoring should focus on environmental features expected to respond to changes in mercury deposition and exposure over management-relevant timescales. Measurements should be made with proven methods, provide data that can be defensibly interpreted, and be optimized to enable differentiation among ecosystem factors related to mercury methylation (e.g., sulfate deposition; mercury loading vs. wetland alteration).

Recommended measurements, as detailed in Harris et al. (2007), include concentrations of total and methylated forms of mercury in air, soils, forest litter, sediments, surface and ground water, snow, yearling fish, adult predatory fish, and mercury-sensitive wildlife species (see appendix D). Monitoring sites should also measure speciated ambient mercury concentrations, wet and dry mercury deposition, and mercury in throughfall and litterfall.

In addition to monitoring changes in mercury concentrations, measurement of ancillary parameters— atmospheric and aquatic chemistry, hydrology, climate, and trophic conditions—is needed to defensibly interpret mercury trends and dynamics. Recommended ancillary measurements include physical features (e.g., watershed area, land cover, wetland area, rainfall), other chemical constituents (e.g., sulfate, nutrients, oxygen, organic carbon) and parameters (e.g., pH, temperature, acid-neutralizing capacity), as well as characteristics of sampled biota (e.g., size, age, trophic position).

III. Types of mercury monitoring sites

Where should mercury parameters be measured?

There is broad agreement about the utility of a nested sampling approach that includes a small number of intensively monitored sites with a larger number of more sparsely monitored sites clustered around them.

Intensive sites are intended to provide a sound foundation for understanding mechanistic, cause-and-effect responses,

“We would like to measure everything everywhere, but that is impractical.”

Rob Mason
University of Connecticut



Table 1. Types of measurements for cluster or intensive sites adapted from Mason et al., 2005. (Note that these recommended measurements may be adapted as the mercury monitoring network is implemented. For more detailed descriptions, refer to appendix D.)

| INDICATOR | SITE | FREQUENCY |
|--|------|-----------|
| Air and Watershed | | |
| Atmospheric mercury speciation; wet and dry deposition flux | IN | C |
| Weekly wet deposition and flux ^a | CL | W |
| Mercury evasion/flux ^a | IN | M |
| Watershed yield (surface water and ground water flux) | CL | M |
| Sediment and Water | | |
| Historic sediment depth profile ^b | IN | I |
| Total mercury, methylmercury, and percent methylmercury in surface (0–2 cm) sediment | CL | S |
| Total mercury, methylmercury in surface water | CL | S |
| Total mercury, methylmercury in water-column profiles | IN | S |
| Aquatic Biota | | |
| Phytoplankton and algae ^c | IN | M |
| Zooplankton/benthic invertebrates ^c | IN | M |
| Yearling fish | CL | A |
| Piscivorous/commercial fish ^c | CL | A |
| Wildlife ^d | CL | A |

Site: IN = intensive sites; CL = cluster and intensive sites

Frequency of sampling: C = continuously; W = weekly; M = monthly; S = every 6 months; A = annually; I = every 3–5 years.

^a Event-based wet deposition collection at intensive sites, weekly integrated sampling at cluster sites. At intensive sites, flux estimates would include wet, dry, gaseous, and particulate deposition; throughfall and litterfall; and snowpack sampling as appropriate. Mercury concentration and evasion fluxes would be for both aquatic and terrestrial environments.

^b Intensive sites and a subset of cluster sites would be sampled to determine historic mercury trends.

^c Sampling not recommended by the biological indicators workgroup at 2003 SETAC workshop (as summarized in chapter 4, Harris et al., 2007).

^d Birds, small and larger mammals; both short-term and integrative sampling.

Note that mercury evasion/flux values frequently change substantially on even an hourly basis. The Draft Standard Operating Procedures for Analysis of Gaseous and Fine Particulate-Bound Mercury, developed from a best practices questionnaire distributed by the NADP, describes standard operation and maintenance of an automated, speciated ambient mercury monitoring unit.

measuring trends, and allowing for development and refinement of models. Emphasis at these sites would be given to process-level monitoring and research and to comprehensive, high-resolution measurements in air, soil, water, and biota. Selection of approximately 20 nationwide intensive sites would emphasize areas likely to undergo change in response to altered mercury loading, highly sensitive sites, and possibly “global background” sites. Capitalizing on existing monitoring programs will maximize opportunities for establishing needed baselines and ongoing institutional support.

Cluster sites are intended to provide a more general understanding of environmental responses for a defined geographic area or ecosystem type, and to allow observations to be transferable to the population of the resource. Emphasis at these sites would be given to expanding geographic coverage of monitoring data through lower resolution and more limited types of measurements than at intensive sites. Approximately 10 to 20 cluster sites would be selected in the vicinity of each intensive site to provide a general understanding of the range of ecosystem responses within the area.

IV. Site selection

What major objectives should guide selection of intensive sites?

Candidate intensive sites will be selected to meet as many network monitoring objectives as possible. However, previous monitoring and research suggests that some candidate intensive sites will have attributes that make them suitable for meeting some monitoring objectives more effectively than others. The following general categories can be used to inform site selection:

Documenting trends. Sites that lend themselves to establishment of baseline mercury concentrations in multiple ecosystem compartments (prior to implementation of atmospheric mercury control measures) will be especially useful for documenting changes in mercury concentrations and determining spatial patterns and long-term trends. Such sites will have existing longer term mercury datasets (both atmospheric and ecosystem data) and supporting information on site characteristics and ancillary measurements (e.g., meteorology). A nationally distributed network of trends sites will be needed to cover a range of ecological regions and span major ecosystem types (e.g., forests, wetlands, streams, lakes, coastal areas, the Great Lakes).

Establishing causality. Sites that are anticipated to exhibit a clearly defined response to changes in mercury deposition (in particular, sites where confounding by other disturbances will be minimal) will be especially useful for establishing mechanistic linkages among changes in atmospheric mercury emissions; deposition rates; and mercury concentrations in soil, water, or biotic compartments. Sites will span a range of expected response times to changing mercury deposition



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(e.g., rapid response in perched seepage lakes, slow response in sites with substantial groundwater input). Study sites will also include areas of high conservation concern and sites near emission sources.

“To have national relevance, we need to have a national distribution of monitoring sites. We have to include definitions of ecosystems that are threatened, including information about ecosystem types, mercury sensitivity, and proximity to sources and urban areas.”

**David Krabbenhoft
U.S. Geological Survey**

Characterizing the influence of other global sources. To differentiate other global (i.e., non-U.S.) sources of mercury from domestic emission sources, it is desirable to include one or more sites that can assist in characterizing, quantifying, and tracking the impacts of atmospheric mercury imported to the United States. It is important to evaluate the influence of mercury from other global sources because emissions are rapidly increasing due to industrialization elsewhere in the world, particularly in China and India. A suitable “global background” site for a national mercury monitoring network would be a location where it can be reasonably assumed from field data and models that mercury inputs are solely or primarily from sources outside of the United States. It is critical that this monitoring network is aware of and tracks other environmental factors—climate, vegetation, soils, land cover, including wetland cover, hydrologic flowpaths, water chemistry, and surface water productivity—that significantly affect mercury transformation and bioaccumulation. Thus, great care will be necessary when identifying one or more “global background” sites for the national mercury monitoring network.

How should modeling needs guide site selection?

Development of models to predict and explain the observed magnitude and timing of ecological responses to changes in mercury emissions (e.g., changing methylmercury levels in fish) requires supporting data. Selection of monitoring sites should be informed by model input needs as well as the need to distinguish the effects of multiple environmental factors.

Watershed Models. For successful application and rigorous testing of watershed mercury models, preferred site characteristics include relatively uniform sites with well-characterized land cover, meteorology, hydrology, soils, and biology, and a relatively long time series of mercury measurements. Data need to include measurement of evasion, throughfall, litterfall, methylation, demethylation, and soil adsorption.

Atmospheric models. For successful development of atmospheric mercury models, preferred site characteristics include simple terrain with few confounding variables (e.g., vehicle traffic), existing meteorological simulations, and well-characterized

regional emission sources that produce a range of atmospheric concentrations and plume “episodes.” Mercury emissions inventories, ambient measurements, and meteorological data are also needed to interpret trends in measurements.

What site characteristics should be used to evaluate potential monitoring sites?

While the rationale for including any individual monitoring site in the national network might be based on unique site characteristics, general considerations for evaluating how well a potential site could contribute to network objectives have been identified. Site selection should be informed by the following criteria:

1. **Sensitivity to mercury inputs.** Ecosystem characteristics (e.g., water quality and land use) play a significant role in determining the “mercury sensitivity” of any potential monitoring location. Mercury sensitivity is the relative efficiency of an ecosystem to transform an inorganic mercury load into bioaccumulated methylmercury. Mercury-sensitive ecosystems are more efficient in conducting the transformation. In addition, it is likely that more sensitive ecosystems will be more responsive to changes in mercury loading in terms of both the magnitude and timing of the response. Chosen monitoring sites will need to have characteristics known to promote greater sensitivity, although some low mercury-sensitivity sites should also be included to quantify the broad range of responses across ecosystem types.
2. **Data and modeling.** Are longer-term mercury or ancillary data available for this site? Does this site have potential for evaluating atmospheric and ecosystem mercury models?
3. **Suitability as a reference site.** Does this site have potential for characterizing the influence of other global sources of mercury?
4. **Site resources.** Does this site have existing scientific facilities and institutional infrastructure to support monitoring? Are there intra-agency and interagency operations and strong prospects for obtaining funding and sustaining monitoring efforts at this site?
5. **Logistical, personnel, and other issues.** Does the site have (or have potential for) access, power supply, and telecommunications? Is this site vulnerable to vandalism or extreme weather? Is this site close to site operators and researchers? Is the land ownership stable?

Design and implementation of a mercury monitoring network will inevitably emphasize coordination across existing monitoring capabilities and infrastructures. Understanding the capacity of current mercury monitoring activities and programs to meet the full range of monitoring objectives and data needs is a key step in building the foundation for an expanded, integrated network.



Mercury Monitoring: What's in Place Now?

High-quality mercury measurements are made in many places throughout the country. From a national perspective, the use of nonstandardized sampling and analytical methods impede assessment of spatial patterns and temporal trends of mercury in the environment. As a first step toward understanding the comparability of mercury sampling data across the United States, EPA, in partnership with the BioDiversity Research Institute and other institutions, developed the MercNet metadatabase. The metadatabase documents information about the location and type of mercury sampling activities nationwide, including methods used to make mercury measurements. The metadatabase was used primarily to identify potential network monitoring sites, based on preliminary analysis of locations where more than one ecosystem compartment (e.g., air, water, fish, sediment) was sampled. The metadatabase is also being used to explore opportunities to standardize network methods on regional and national scales.

I. Existing mercury monitoring programs and sites

What monitoring programs are already in place?

Mercury monitoring efforts vary greatly across the United States, ranging from one-time sampling events, to repeat long-term sites that monitor mercury in one ecosystem compartment, to established intensive study sites that monitor mercury in the atmosphere, surface water, fish, sediment, vegetation, wildlife, and other environmental media. (See appendix B for a summary of major existing and emerging monitoring initiatives.) Monitoring efforts conducted by researchers, federal agencies, states, tribes, and other organizations to support distinct objectives are often uncoordinated and use disparate sampling and analytical methods. In many instances, resulting mercury data from these efforts are not entirely comparable. This can present a challenge to establishing regional and national baselines, assessing spatial patterns and temporal trends, and evaluating causal links between mercury emissions and bioaccumulation in aquatic food webs.

“MercNet can be considered a shared resource for everyone and will provide a valuable benchmark for future needs by scientists, landscape managers, and policymakers.”

David Evers
BioDiversity Research Institute

Where has mercury data been collected?

To characterize the landscape in which a national mercury monitoring network could be implemented and to identify gaps in data gathering, EPA's Office of Atmospheric Programs and the BioDiversity Research Institute have catalogued sites where mercury concentrations and related parameters have been measured nationwide. The MercNet metadatabase houses information about the geographic location, dates, and other attributes of mercury sampling events in various media such as air, water, sediment, fish, plants, and wildlife conducted by many agencies and researchers.

The metadatabase was populated through several approaches, including a broad survey of scientific literature, data mining from federal agency datasets,⁷ and informally surveying

⁷ These include: NOAA National Status and Trends Program (NS&T), EPA Environmental Monitoring and Assessment Program (EMAP), EPA STORage and RETrieval (STORET), USFWS Environmental Contaminant Data Management System (ECDMS), USGS National Water-Quality Assessment Program (NAWQA), USGS Contaminant Exposure and Effects-Terrestrial Vertebrates (CEE-TV), and BioDiversity Research Institute (BRI) Wildlife Data.



Photo credit: Mario Montesdeoca, Syracuse University



Mercury Monitoring: What's in Place Now?

the research community.⁸ This resource might be used to search for potential intensive or cluster sites that meet key monitoring objectives, as well as to identify major gaps in existing monitoring coverage. Preliminary queries of the MercNet metadatabase were conducted to demonstrate its potential for identifying sites that could be appropriate for trends analysis—by identifying sites with repeat sampling—and sites that might be appropriate for establishing causality—by identifying sites with measurements for multiple environmental compartments. Sites with higher resolution ecological analysis have overlapping measurements for fish and other wildlife, as well as for information about mercury concentrations associated with adverse biological effects.

Future applications of the MercNet metadatabase might include identification and analysis of data suitable to support development of mercury baselines. However, more work is needed to fully populate the metadatabase and evaluate the mercury datasets.

II. Potential intensive sites

What has been done to characterize potential intensive sites?

A key step in implementing a national mercury monitoring network is to select intensive sites where a broad suite of mercury and ancillary measurements should occur.

⁸ These include: Syracuse University comprehensive mercury monitoring activities at Huntington Wildlife Forest and Sunday Lake in the Adirondacks; sediment core mercury monitoring activities in the upper Midwest; over 100,000 records for fish-sampling activities, including data from state environmental agencies/departments, USGS programs (e.g. NAWQA, BEST), and private research institutions.

A compilation exercise to characterize current sampling programs at existing mercury monitoring sites was performed by staff in EPA's Office of Atmospheric Programs. While not yet complete, this compilation was intended to synthesize background information and allow objective site comparisons based on the richness of monitoring data collected at each site and suitability for meeting monitoring objectives. Rich datasets produced by site-specific mercury research are a valuable asset; however, the stability of funding for continued data collection will be a key consideration in selecting intensive sites.

To identify sites with strong potential for contributing to a national monitoring network, the list of recommended measurement parameters (from Harris et al., 2007) and site selection criteria (described on pp. 13–14) were applied to existing monitoring sites. Specifically, sites in the MercNet metadatabase, sites identified through the primary literature (approximately 120 journal articles), and sites in known monitoring networks⁹ were filtered to identify geographic locations where more than one ecosystem compartment (e.g., air, water, fish, sediment) is measured within a defined area.

A preliminary, semi-qualitative assessment led to the identification of 69 potential intensive sites for evaluation by the Data Task Group (see p. 17). Notably, results of this initial compilation suggest that most sites have better potential to function as cluster sites than as intensive sites.

A key objective of the Annapolis workshop was to refine selection criteria and identify candidates for a comprehensive mercury monitoring network of intensive and cluster sites, based on agreed upon network elements and objectives. In preparation for the workshop, the Steering Committee convened the Data Task Group on March 4, 2008, to undertake a planning exercise for identifying potential monitoring sites based on preliminary site characterizations developed by EPA. In breakout groups and full group discussions, participants at the Annapolis workshop reflected on the preliminary options developed by the Data Task Group and helped to more fully characterize potential intensive and cluster sites.



Photo credit: Adirondack Ecological Center

⁹ Such as the National Atmospheric Deposition Program (NADP), the Clean Air Status and Trends Network (CASTNET), and the Temporally Integrated Monitoring of Ecosystems (TIME).



Developing the Mercury Monitoring Network: Selecting Sites

Workshop participants evaluated preliminary intensive site characterization and selection work performed by the Data Task Group. Outcomes included a refined list of potential intensive sites and identification of next steps for further refinement. Additional work is needed to refine definitions of intensive sites (e.g., appropriate areal extent) and cluster sites (e.g., geographic criteria, national consistency). Characterization and selection of intensive sites require evaluation of sites' existing and potential monitoring activity as well as the ability to meet network objectives. Participants also explored general issues, potential criteria, and alternative approaches for selection of cluster sites.

“We [the Data Task Group] tried to identify and characterize existing sites through a series of criteria, including distribution, sensitivity to mercury deposition, proximity to sources (i.e., elevated loading), previous studies and monitoring, conservation concerns, and the region around the sites.”

Charles Driscoll
Syracuse University

I. Preliminary intensive site selection

What progress has been made in selecting intensive sites?

Based on their professional judgment and the preliminary compilation of existing sites described above, the Data Task Group developed a list of 21 candidate sites to further characterize and review at the Annapolis workshop. The group focused on identifying a limited set of potential intensive monitoring sites that would represent key site types and meet a range of network monitoring objectives and site selection criteria. The group recommended further site characterization and a gap analysis to examine the monitoring capacity of each potential site relative to network monitoring objectives and siting considerations.

Data Task Group members noted that it was difficult to identify existing sites where the full range of measurements needed to meet overarching network objectives were currently being made. However, a number of sites were included by multiple experts in their recommended sites lists (developed in preparation for the March 4th meeting).

At the Annapolis workshop, participants worked in breakout groups—based on geographic regions—and in full group discussions to evaluate the proposed list of 21 intensive sites and expand the underlying site characterization (e.g., by applying region-based knowledge of specific sites). These discussions produced a next iteration of candidate intensive sites (appendix C). This preliminary list will be explored through regional meetings and further refined by network planners.

What issues remain unresolved for intensive sites?

Discussions by the Data Task Group and Annapolis workshop participants outlined a set of questions that should be addressed to support further development of the list of potential intensive sites:

1. The list of potential intensive sites includes ‘sites’ that range widely in geographic extent from fairly localized areas with established monitoring to multi-state regions. Further work is needed to define the areal extent that is considered appropriate for a designated intensive site. For example, is it possible and appropriate to combine adjacent sites with complementary data into a single large site? A geographic definition has implications for the range of landscape variability that is included within a designated intensive site, as well as the pool of historical mercury and ancillary data that would be considered relevant.
2. Selection of intensive sites will draw upon a number of considerations, and some degree of prioritization among these might be necessary. For example, what are the tradeoffs in site selection to achieve objectives of documenting trends versus establishing causality? Some types of data collection (e.g., atmospheric, biota) might lend themselves more easily to establishment of baselines, and this might affect comparisons of potential sites with different types of baseline data. The answer may depend on whether the site is selected to establish trends—and therefore requires strong baseline data—or to determine causal links between mercury deposition and ecological response.
3. Agreement is needed about how to evaluate sites that are well suited to meeting a single monitoring objective relative to sites that provide a more balanced set of capabilities. For example, should a site be included in the small set of intensive sites with a primary site objective

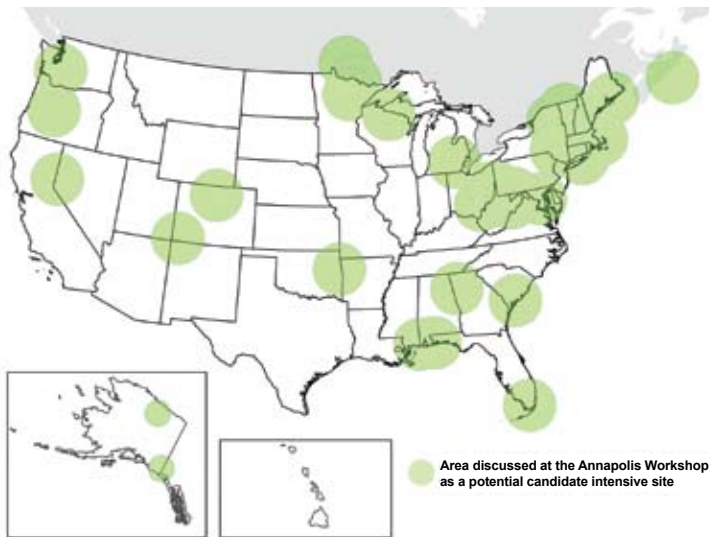


Figure 4. Conceptual map of a potential mercury monitoring network. This map illustrates how monitoring sites could be distributed across the United States to achieve comprehensive regional and national coverage. (Note: The areas identified in this map are preliminary and do not represent a final set of sites to be included in the national mercury monitoring network.)

of characterizing the influence of other global sources if it does not contribute usefully to other monitoring network objectives?

What are the next steps toward selection of intensive sites?

Although preliminary characterization of potential intensive sites has been used to inform stakeholder efforts to select a useful set of sites, more in-depth and quantitative site characterization is needed. For each of the candidate intensive sites, substantial work is needed to fully characterize current and potential monitoring capacity and evaluate how the site would contribute to network monitoring objectives. This will involve evaluating the coverage of recommended measurement parameters, as well as potential confounding factors, at a more comprehensive set of existing sites and performing some form of geographic gap analysis to understand where existing monitoring infrastructure is lacking. Selection of the full set of intensive sites requires definition of the geographic regions to be used in distributing sites across the United States. As part of a geographic analysis, basic site categorization by ability to support documentation of trends and establish causal links between mercury emissions and ecological response will be critical to ensure the national network can meet the core objectives with robust spatial relevance.

II. Cluster site selection

What progress has been made in cluster site selection?

The Data Task Group also discussed several different approaches for selecting cluster sites. The proposed objectives to guide cluster site selection include assisting in national assessments and evaluation of policy impacts, contributing to ecological baselines, and providing information needed for model development and process-level research. At the Annapolis workshop, presentations and discussions explored key concepts and tradeoffs in locating cluster sites. Presenters provided alternative approaches for optimizing selection of cluster site locations, anchored in case studies of specific existing monitoring efforts.

Random Stratified Sampling Design—Case Study in the Everglades. To illustrate the utility of cluster siting based on random sampling sites established through major monitoring programs, David Krabbenhoft (U.S. Geological Survey) described the extensive sampling program for mercury in the Florida Everglades. The U.S. Geological Survey led a study to monitor nine intensive sites running north-south through the Everglades over time. Beginning in 1995, a fleet of helicopters was used to do random stratified design sampling to spatially extrapolate from these nine intensive sites, through EPA's Regional Environmental Monitoring and Assessment Program (REMAP) with multi-agency support. The intensive and cluster site monitoring in the Everglades program has enabled the following important observations: (1) methylation rate varies across the landscape and corresponds closely to mercury abundance; and (2) between 1995 and 2005, 20 percent of the land area that formally exceeded human health benchmarks for mercury in tiny fish are no longer exceeding those levels. It is believed that a decrease in sulfate entering the Everglades has played a key role.

Ecosystem Subtype Sampling Design—Case Study in Acadia National Park. To illustrate how cluster siting could account for spatial variability around intensive sites, David Evers (BioDiversity Research Institute) presented ideas for siting mercury monitoring in the vicinity of Acadia National Park on Mount Desert Island in Maine. This area has diverse habitat and a range of existing mercury-related biological datasets. The emphasis in this presentation was on connecting mercury data gathering to different habitat types and food webs—with different levels of mercury sensitivity—and locating cluster sites to track how mercury has moved through freshwater, terrestrial, and marine habitats. This approach, it was noted, represents a more geographically constrained strategy.



Process-Level Sampling Design—Case Study in the Adirondacks. To illustrate the benefits of process-level sampling strategies, Charles Driscoll (Syracuse University) described intensive and cluster monitoring sites in the Adirondacks region of New York. This large forested area includes an intensive study site at the Huntington forest, a 300-hectare area with an NADP National Trends Network site, and a Mercury Deposition Network (MDN) site for mercury data collection. Process-level studies in uplands, wetlands, and lakes have used mass balance and tracer studies to understand the processing and transport of mercury across the landscape. A series of lakes (and surrounding terrestrial areas) were monitored in the early 1990s and later to document physical and chemical changes through measurements of total mercury, methylmercury, pH, sulfate, and other information. Resulting observations were mixed: mercury concentrations in fish decreased in half the lakes, increased in one-quarter of the lakes, and remained unchanged in one-quarter of the lakes.

“The clearest change in the deposition of mercury that can be biologically measured is likely in terrestrial systems, primarily because there are fewer biogeochemical hurdles for detecting a clear response. Even though ecological risk is likely greatest in wetlands, mountaintops may be the best habitat to monitor such changes.”

David Evers
BioDiversity Research Institute

Atmospheric Modeling Sampling Design. Mark Cohen (National Oceanic and Atmospheric Administration) described key concepts for locating and designing atmospheric measurement cluster sites. For areas that are remote from major emission sources, spatial gradients in atmospheric concentration and deposition might be relatively small; therefore, the need for cluster sites may be minimal. That is, measurements at the intensive site may be reasonably representative of the surrounding areas. However, for source-impacted areas, there may be large spatial gradients. While MDN-type cluster sites measuring wet deposition may be cost effective, it would be prohibitively expensive—with currently available approaches—to measure ambient concentrations and rigorously estimate dry deposition at a sufficient number of cluster sites to characterize the atmospheric concentrations and total deposition in the area surrounding the intensive site. Thus, for the atmospheric pathways, models will be crucial, and to the extent possible, atmospheric intensive and cluster site design should optimize development, evaluation, and improvement of atmospheric fate and transport models. From the modeling perspective, it would likely be more useful to have a few “comprehensive” measurement sites than a number of cluster sites with very incomplete measurements (e.g., wet

deposition only). In considering where to locate intensive sites and any surrounding comprehensive atmospheric cluster sites, ideal sites would be ringed by different sources and therefore be affected by episodic high levels of mercury deposition from known sources as well as regional and distant (global) sources.

“You cannot measure everything that you want to measure everywhere, which is why models are necessary. Given resource constraints, a few comprehensive monitoring sites may be more useful for atmospheric model development and evaluation than a lot of minimally instrumented cluster sites.”

Mark Cohen
National Oceanic and Atmospheric Administration

What issues remain unresolved for cluster sites?

It is anticipated that selection of cluster sites will occur after selection of intensive sites, yet some conceptual guidance is needed to advance the selection process. Discussions by the Data Task Group and Annapolis workshop participants clarified the set of considerations and challenges yet to be resolved to develop selection criteria:

1. The definition of geographic criteria for cluster sites should specify the maximum distance of cluster sites from intensive sites that is considered useful for extending the spatial relevance of measurements at intensive sites. Consideration should be given to how map-based proximity analyses can be used to consider monitoring within a certain radius from potential intensive sites.
2. Geographic definitions will affect the degree to which intensive sites and their associated cluster sites provide comprehensive spatial coverage across the United States. Some specific questions:





Developing the Mercury Monitoring Network: Selecting Sites

- Should the full set of cluster sites be located to achieve comprehensive national representation (i.e., cluster sites “fill in” areas across the entire United States)? Or should cluster sites be optimized to support process-level research conducted at individual intensive sites by more fully characterizing localized variability?
 - Should cluster sites be selected to achieve characterization of ecological regions?
 - How should plans for modeling to achieve spatial extrapolation be incorporated into site selection? How should down-scaling capability be included?
3. Guidance is needed with regard to how cluster sites should be chosen to account for variability in landscape and habitat types around intensive sites. For example, is it more important that cluster sites represent all major ecological systems surrounding an intensive site, or that they represent those ecological systems most sensitive to changing mercury deposition (and related factors)?
 4. Ideally, cluster sites would be located in a highly consistent manner across the country; however, regional differences in landscape type might affect the comparability of cluster sites and the information they contribute to a national monitoring network. For example, in some areas, the absence of natural lakes might inhibit establishment of cluster sites as they have been defined to date. Further clarification is needed regarding how to maximize consistency in cluster site selection while allowing room for regionally appropriate selection strategies.
 5. Finally, as the small set of intensive sites are identified, selection of cluster sites will require choices about maximizing the use of existing probabilistic monitoring networks to provide data for ancillary parameters or optimizing for sites that best align with mercury monitoring objectives.





Opportunities for Collaboration: Next Steps

Agreement emerged from the Annapolis workshop regarding mercury monitoring network goals, objectives, and major design elements. In the final workshop session, participants came to agreement about how to focus collaborative efforts in the near term. Refinement of the monitoring network design will emphasize creation of a national framework for site selection and data sharing. Network planners will seek opportunities to leverage existing monitoring activities and funding sources through engagement with the broader mercury community. Outreach and support-building for existing and expanded monitoring will inform federal and state decision-making.

A number of areas of agreement emerged from the Annapolis workshop. Goals and objectives for the monitoring network were refined to include greater focus on provision of information to key policy and management audiences and linkage to emission control policies. A nested sampling approach, based on intensive and cluster sites that emphasizes coordination of existing monitoring capabilities and infrastructure achieved broad agreement. The need to move forward in developing an integrated national monitoring system that produces comparable and high-quality data, and to establish baseline information in advance of impending changes in mercury regulations and emissions, was widely acknowledged.

At this time, major new funding programs for expanded mercury monitoring are unavailable, and additional network design issues remain. However, opportunities exist in the near term to move forward in building the foundation of a national mercury monitoring network. Expanded collaboration to integrate existing and emerging monitoring activities through a national network can substantially improve the delivery of nationally consistent mercury data.

With representation by federal agencies, states, and tribes, as well as academic and private-sector scientists, network planners are poised to further develop the national monitoring network through a range of partnerships. Key activities will likely include convening subcommittees and task groups to address network design challenges, engaging the mercury community and reaching out to potential supporters, and identifying opportunities to build new monitoring capacity.

I. Refining network design

A national framework

There is a clear need for a national framework to guide the integration of local, state, tribal, federal, private, and research-scale mercury monitoring efforts into a nationally coherent network. In addition to identifying intensive and cluster sites, such a framework should provide mechanisms for harmonizing data from existing monitoring programs, as well as informing implementation of emerging monitoring efforts. As a diverse consortium of monitoring efforts that adhere to common sampling and data management protocols to routinely deliver high-quality, nationally consistent environmental data products, the NADP provides a useful organizational model.

Site evaluation and selection

Intensive sites. Workshop participants saw a clear need for quantitative assessment of the ability of potential intensive sites to meet monitoring objectives, and for a consistent description of the rationales for inclusion of specific sites in the network. Building on the MercNet metadatabase and other preliminary work, participants recommended continued compilation of site characteristics for a broader range of existing North American monitoring sites and programs.

“We need someone to pull data together to get a good product. The Northeast area did a great job. We need to scale up and bring the information together so that we can make regional or national assessments, as opposed to the current piecemeal approach.”

Darren Rumbold
Florida Gulf Coast University

Workshop participants also widely acknowledged that a wealth of mercury data has been collected at many potential intensive sites over time—although in many cases the absence of repeat sampling or other limitations constrains the utility of data for meeting national monitoring objectives. Some assessment of the opportunities for creating high-value information, such as mercury baselines, by further mining of existing literature and databases should be part of rich site characterization. With leadership from network planners,



a mechanism will be needed for selecting intensive sites for inclusion in the network once richer characterization work has been completed.

Cluster sites. While substantial progress has been made in identifying selection criteria and specific potential intensive sites, more work is needed to produce similar progress for selection and identification of cluster sites. Network planners will work with stakeholders to clarify the characteristics and deliverables that will be expected from a cluster site in the national mercury monitoring network. Similar to intensive sites, a mechanism for cluster site selection will be needed—such a mechanism could be located at the level of major regions or even individual intensive sites if clear guidance is available to ensure national consistency.

Integrating monitoring data and emerging monitoring efforts

Development of specific technical resources for integrating mercury monitoring data is needed to build on the expanding interest and activity for mercury monitoring at many levels. To guide monitoring by individual states, tribes, and other site operators, a manual that outlines common protocols for collection, configuration, storage, and quality control of data is an essential tool for producing nationally consistent datasets.

Historically, many types of environmental research and monitoring data have not been made widely available beyond the data-gathering institution or agency, and this has constrained our ability to more fully understand mercury dynamics. To facilitate data exchange, a clearinghouse for mercury data that standardizes existing datasets could be developed with the MercNet metadatabase as a platform. Development of data-sharing mechanisms and cooperation with national monitoring and research programs such as the NADP or the National Ecological Observatory Network could contribute to this effort.

II. Community engagement and outreach

Engaging the mercury research and monitoring community

While the May 2008 Annapolis workshop was an important step in building broad support around a conceptual design for a comprehensive, integrated monitoring network in the United States, many researchers and natural resource managers across the country have not yet been engaged in network design efforts. These individuals and their agencies

and institutions can enhance characterization of potential monitoring sites and identify opportunities for leveraging existing data-gathering activities and funding sources to efficiently and effectively meet network objectives.

Strategic engagement and collaboration will be fostered through sessions at national meetings (e.g., NADP's annual scientific symposium), as well as specially convened regional meetings. These meetings will provide opportunities to engage regional experts who can provide richer information about the possibilities and constraints of existing sites, as well as areas for consideration for establishment of new monitoring activity. By engaging broader stakeholder groups within regional contexts, it may be possible to lay the foundation for regionally based evaluation and selection of cluster sites.

Reaching out to potential supporters

Throughout the workshop, discussions emphasized the importance of communicating the need for improved and expanded mercury monitoring beyond the mercury research and monitoring community. To assist in communicating with policymakers and potential funding entities about the need to develop a comprehensive mercury monitoring network, participants recommended producing and distributing several straightforward and engaging communications pieces to key audiences through briefings, conferences, and other settings. In addition, these materials can assist in building institutional support within federal and state agencies for long-term datasets and regular information products by clarifying the rationale for sustaining existing efforts. This report serves as one product. An executive summary of this report serves as a fact sheet or brochure.

III. Building new monitoring capacity

As the network design and suite of monitoring sites are refined, gaps in geographic coverage and mercury measurements will likely be identified. To fill these gaps, new monitoring capacity and the resources to support it will be needed. In some cases, this might involve implementing new mercury measurement capability at existing facilities where baseline information and ongoing data collection already are in place. In other cases, this might require the establishment of new monitoring sites to fill in geographic gaps. As new funding sources become available, implementation of new monitoring infrastructure will provide important new capabilities for tracking changing mercury levels and understanding ecological and human health effects.



List of Appendices

- A. Workshop Steering Committee and Participants**
- B. Mercury and Ancillary Monitoring Programs**
- C. Preliminary List of Candidate Intensive Sites—from Annapolis Workshop**
- D. Tables of Recommended Mercury and Ancillary Measurements**
- E. Glossary of Terms**



Photo Credit: Joseph Bushey, Syracuse University



Appendix A

Workshop Steering Committee and Participants

National Mercury Monitoring Workshop Steering Committee

Rick Artz, National Oceanic and Atmospheric Administration
Tom Atkeson, Florida Department of Environmental Protection
Ryan Callison, Cherokee Nation
Charles Driscoll, Syracuse University
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David Gay, National Atmospheric Deposition Program
Rick Haeuber, U.S. Environmental Protection Agency
Dave Krabbenhoft, U.S. Geological Survey
Rob Mason, University of Connecticut
Greg Masson, U.S. Fish and Wildlife Service
Kristi Morris, National Park Service
David Schmeltz, U.S. Environmental Protection Agency
Ed Swain, Minnesota Pollution Control Agency

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Jim Wiener, University of Wisconsin-La Crosse



Appendix B

Mercury and Ancillary Monitoring Programs

This compilation represents information shared at the Annapolis workshop about major existing and emerging monitoring programs and does not account for all programs and efforts that monitor mercury in the United States.

| AGENCY/PROGRAM | MERCURY MONITORING ACTIVITY |
|---|---|
| National Atmospheric Deposition Program (NADP), Mercury Deposition Network (MDN) | NADP currently monitors mercury in wet deposition at more than 100 MDN sites throughout North America. Under the new NADP Atmospheric Mercury Initiative, federal agencies (e.g., EPA, USGS, NOAA), states, tribes, universities, and other institutions are collaborating to measure air concentrations of mercury in its gaseous and particulate forms. Data generated are used to support mercury dry deposition estimates, assessment of mercury source impacts, atmospheric model evaluation, and long-term trends assessment. Fifteen sites are currently participating, with several more expected to join in 2009. Participants operate mercury speciation instrumentation in accordance with a standard operating procedure developed by NADP and the mercury measurement scientific community. NADP maintains quality-assured site data in a centralized database. Data will be available online at http://nadpweb.sws.uiuc.edu/amn/ . |
| U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) | Detailed mercury cycling studies in streams in Oregon, Wisconsin, Florida, the coastal plain of South Carolina, and the Adirondacks monitor food web, water quality, sediment geochemistry, and wet deposition. Currently developing models of mercury transport and cycling for South Carolina and New York studies, in collaboration with EPA. Large-scale synoptic studies use one-time sampling of mercury in the water column, sediments, and fish tissue at several hundred stream sites across the United States. Selected other USGS mercury studies have been done for Lake Champlain tributaries, California streams and rivers, high-elevation lakes in the West, and lakes in northern Minnesota (Voyageurs National Park). |
| National Oceanic and Atmospheric Administration (NOAA) | Monitoring and modeling of mercury in air, water, sediments, and biota in U.S. coastal regions and the Great Lakes focuses on understanding the fate and cycling of mercury. Atmospheric measurements are gathered at several long-term sites and via aircraft. Several NOAA programs gather data on mercury in biota. Mussel Watch provides a long-term, nationwide dataset for mercury in bivalves. Fish and dolphin monitoring data have been gathered for regional and national surveys. Additional work looks at mercury in seafood, as well as integrated ecological assessments. |
| National Park Service (NPS) | NPS hosts 14 MDN sites at different parks across the United States. Extensive studies on the ecological effects of mercury have been completed or are in progress at several national parks. The recently completed, 5-year Western Airborne Contaminants Assessment Project (WACAP) examined mercury and other contaminants in air, snow, water, sediments, lichen, conifer needles, and fish at eight parks in the western United States: Denali, Gates of the Arctic, Glacier, Mount Rainier, Noatak, Rocky Mountain, Glacier, and Sequoia. The final report is available at www.nature.nps.gov/air/Studies/air_toxics/wacap.cfm . |



Appendix B

| AGENCY/PROGRAM | MERCURY MONITORING ACTIVITY |
|---|--|
| <p>U.S. Environmental Protection Agency (EPA)</p> | <p>EPA supports several collaborative monitoring programs:</p> <ul style="list-style-type: none"> ■ The EPA Office of Air and Radiation (OAR) collaborates with the NADP and other and other organizations to establish a new, national, standardized network to monitor mercury in the atmosphere (see above). Related to NADP, EPA-OAR administers the Clean Air Status and Trends Network (CASTNET), a long-term network of more than 80 atmospheric monitoring sites that provide ancillary measurements useful for mercury monitoring and model development. ■ The EPA Office of Water (OW) recently initiated the National Rivers and Streams Assessment, which will include fish tissue sampling for mercury. Field collection will occur over 2 years (2008–2009) at approximately 2,000 sites including wadeable and non-wadeable water bodies. EPA-OW has also been working with states to standardize protocols for monitoring mercury in water. ■ The EPA Office of Research and Development (ORD) is conducting an ongoing investigation of mercury fish tissue concentrations. In 2005, ORD re-sampled 42 sites from the original Mid-Atlantic Highlands Assessment (MAHA), where fish-tissue mercury samples were collected in 1993–1994. In 2005, ORD sampled 60 Temporally Integrated Monitoring of Ecosystems (TIME) sites in the mid-Atlantic region for the first time for fish tissue mercury. ORD intends to re-sample these sites for fish tissue mercury every 2–3 years, as funds allow. |
| <p>States</p> | <p>States have expended more than \$50 million on mercury research and monitoring over the past 15 years. The primary focus has been on studies of mercury in fish and other biota, mercury emission inventories, lake sediment core analyses, atmospheric deposition modeling and monitoring, and research on mercury attributable to consumer products.</p> <p>Of 47 states, two tribal agencies, and one Canadian province that responded to a recent survey (percentages refer to proportion of respondents for each question):</p> <ul style="list-style-type: none"> ■ All have fish consumption advisories because of mercury in fish. ■ 94 percent have ongoing fish contaminant monitoring programs (FCMPs). ■ In 67 percent, the FCMP is intended only for fish consumption advisories. ■ 63 percent use FCMP data for trend analysis. ■ 65 percent use trend monitoring at fixed stations (x-sites every y-years); all but two of these fixed station FCMPs have a 1 to 5- year sample cycle. ■ The average period of record for monitoring is 14 years. ■ 54 percent have prepared monitoring reports. ■ 60 percent use largemouth bass as the indicator fish species, 37 percent use walleye, and 33 percent use trout species. <p>(Based on 2008 surveys of states by C. Mark Smith, Massachusetts Department of Environmental Protection, and Bruce Monson, Minnesota Pollution Control Agency)</p> |
| <p>Tribes</p> | <p>Tribes with MDN sites: Potawatomi Nation, WI; Menominee Indian Tribe of Wisconsin; Cherokee Nation (Stillwell, OK; Newkirk, OK); Yurok Tribe, CA; Makah Nation, WA; Cheyenne River Sioux Tribe, SD; Grand Traverse Band of Ottawa and Chippewa Indians, MI; Micmac Tribe, ME; Sac and Fox Nation, KS. Pending MDN sites: Penobscot Nation, ME. Possible MDN sites: Mille Lacs Band of Ojibwe, MN (might start again); Zuni Nation, NM. Inactive MDN sites: Mille Lacs Band of Ojibwe, MN; Passamaquaddy, ME.</p> <p>Several tribes are monitoring mercury in fish and other media within their tribal lands.</p> |



APPENDIX C

Preliminary List of Candidate Intensive Sites—From Annapolis Workshop

This list represents the recommendations from regionally based breakout groups at the Annapolis workshop and does not represent the final list of intensive monitoring sites to be proposed for inclusion in a national network. Further characterization of these and other potential intensive sites is planned (see details on pages 18 and 21). Parentheses indicate sites that the breakout groups considered to be of secondary priority.

Southeast

Everglades National Park, FL
 Coastal South Carolina [ACE Basin]
 Northern Gulf Coast
 Grand Bay NERR, MS
 Pensacola, FL
 (Atlanta/Yorkville, GA)

Mid-Atlantic

Chesapeake Bay [Beltsville, SERC]

Northeast

Huntington Wildlife Forest, NY
 Acadia National Park, ME
 Proctor Center, Underhill, VT
 Neversink Watershed, NY
 Cape Cod National Seashore, MA
 Long Island Sound, NY
 (Mt. Washington, NH)
 (Kejimkujik, NS)

Ohio River Valley

Steubenville, OH
 (Frostburg, MD)
 (Canaan Valley Institute, WV)
 (Athens, OH)

Upper Midwest

Voyageurs National Park, MN
 Experimental Lakes Area, Canada
 Dexter, MI
 Marcell Experimental Forest, MN
 (Northern Highland Forest, WI)

West

Rocky Mountain National Park, CO
 Toolik, AK
 Glacier Bay, AK
 Stilwell, OK
 Sierra Nevada, CA/NV
 Mt. Rainier, WA
 (Four Corners-Mesa Verde, CO)
 (Mt. Bachelor, OR, as a “global background” site)



APPENDIX D

Tables of Recommended Mercury and Ancillary Measurements

Note that these recommended measurements may be adapted as the mercury monitoring network is implemented.

MERCURY MEASUREMENTS FOR DOCUMENTING TRENDS—ADAPTED FROM TABLE 6.2, P. 199 IN HARRIS ET AL., 2007

| INDICATOR | LOCATION (INTENSIVE, CLUSTER, OR BOTH) | FREQUENCY |
|--|--|------------------------------------|
| Soil solutions (Total Hg and MeHg) | Intensive | Quarterly |
| Sediment (Total Hg and MeHg) | Both | Annual and quarterly, respectively |
| Percent MeHg in sediment | Both | Annual and quarterly, respectively |
| Instantaneous methylation rate | Both | Annual and quarterly, respectively |
| Total Hg accumulation rate in sediment | Cluster | Every 5-10 years |
| Surface water (Total Hg and MeHg) | Both | Annual and quarterly, respectively |
| Stream | Intensive | Weekly |
| Total Hg in whole prey fish | Both | Annual or semi-annual |
| Total Hg in predatory fish (axial muscle) ^b | Both | Annual |
| Total Hg in mammal blood and fur ^a | Both | Annual |
| Total Hg in bird blood, feather, and egg ^a | Both | Annual |

^a Species of birds and mammals vary in distribution and habitat preferences and can only be used as indicators where present.

^b Not included in Table 6.2 in Harris et al., 2007.



Appendix D

MERCURY MEASUREMENTS FOR ASSESSING CAUSALITY—ADAPTED FROM TABLE 6.3, P. 200 IN HARRIS ET AL., 2007

| INDICATOR | LOCATION (INTENSIVE, CLUSTER, OR BOTH) | FREQUENCY |
|--|--|----------------------------|
| Atmospheric Hg | Intensive | Continuous |
| Wet deposition (Total Hg) | Intensive | Weekly |
| Throughfall (Total Hg and MeHg) | Intensive | Weekly |
| Litterfall (Total Hg and MeHg) | Intensive | Weekly |
| Snowpack (Total Hg) | Cluster | Annual |
| Soil (Total Hg and MeHg) | Intensive | Once to characterize pools |
| Soils solutions (Total Hg and MeHg) | Intensive | Quarterly |
| Forest floor surveys | Intensive | 10 years |
| Sediment (Total Hg and MeHg) | Both | Quarterly |
| Percent MeHg in sediments and soils | Both | Quarterly |
| Instantaneous sediment methylation rate | Intensive | Biannual |
| Total Hg accumulation in cores (Total Hg and MeHg) | Intensive | 5-10 years |
| Ground water (Total Hg and MeHg) | Intensive | Quarterly |
| Surface water (Total Hg) | Both | Quarterly |
| MeHg/Total Hg ratio in surface water | Both | Quarterly |
| Raccoon | Cluster (when feasible) | Annual |
| Mink | Both (when feasible) | Annual |
| Harbor porpoise | Cluster (when feasible) | Annual |
| Common loon | Both (when feasible) | Annual |
| Herring gull | Cluster (when feasible) | Annual |
| Common tern | Cluster (when feasible) | Annual |
| Leach's storm petrel | Cluster (when feasible) | Annual |
| Belted kingfisher | Both (when feasible) | Annual |
| Tree swallow | Both (when feasible) | Annual |
| Bicknell's thrush | Cluster (when feasible) | Annual |
| Saltmarsh sharp-tailed sparrow | Cluster (when feasible) | Annual |

Note: Species of birds and mammals vary in distribution and habitat preferences and can only be used as indicators where present.



ANCILLARY MONITORING PARAMETERS—ADAPTED FROM TABLE 6.4, P. 204 IN HARRIS ET AL., 2007

| PARAMETER | LOCATION (INTENSIVE, CLUSTER, OR BOTH) | FREQUENCY | TYPE (A OR B) ^a |
|--|---|--|-------------------------------|
| Atmospheric deposition of sulfate | Both | Weekly | B |
| Rainfall | Both | Weekly | B |
| Watershed area | Both | Once | B |
| Land cover | Both | Once | B |
| Percent wetlands in watershed area | Both | Once | B |
| Lake morphometry | Both | Once | B |
| Water chemistry (pH, dissolved organic carbon, sulfate, total suspended solids, chlorophyll, temperature, acid-neutralizing capacity, color, nutrients, dissolved oxygen, stratification status) | Both | Quarterly | A, B |
| Characteristics of fish (size, age, stomach contents, sex, condition) | Both | Annual for prey fish; 1 to 3-year intervals for piscivorous fish | A, B |
| Characteristics of mammals (size, age, sex, condition) and tissues for nonlethal sampling (fur and blood) and lethal sampling (fur, brain, muscle, and liver) ^b | Both | Annual | A, B |
| Characteristics of birds (size, age, sex, condition) and tissues for nonlethal sampling (blood, feathers, and eggs) and lethal sampling (feathers, brain, muscle, liver, and eggs) ^b | Both | Annual | A, B |

^a Type A = for trends assessment; Type B = for causality assessment

^b Species of birds and mammals vary in distribution and habitat preferences and can only be used as indicators where present.



Appendix E

Glossary of Terms

Ancillary measurements: Environmental measurements that supplement data on mercury concentrations to accurately characterize mercury trends and dynamics. Examples include weather patterns; physical features of watersheds; chemical constituents of air, soil, and water; and characteristics of sampled organisms. See appendix D for more detailed description of recommended ancillary measurements.

Atmospheric deposition: Transfer of pollutants, such as mercury, from the air to vegetation, soil, water, and the built environment through wet (e.g., rain, snow) and dry (e.g., falling particles, gas exchange) mechanisms.

Baseline: Initial comprehensive environmental measurements against which subsequent measurements, made using the same protocols and techniques, can be compared.

Biota: The biological organisms, including microbes, plants, and animals, inhabiting a given area.

Cluster sites: Locations in the vicinity of an intensive site where a limited set of environmental measurements are made in order to expand the geographic relevance of intensive measurements.

Ecosystem sensitivity: Ecosystem properties (e.g., abundance of wetlands) that increase the likelihood of mercury movement, methylation, and uptake by organisms.

Intensive sites: Locations where comprehensive, high-resolution measurements are made in air, soil, water, and biota to produce a robust understanding of ecological responses to changes in mercury loading.

Mercury bioaccumulation: Increased concentration of mercury in the tissues of an organism.

Mercury biomagnification: Increased concentration of mercury in the tissues of organisms at higher trophic levels of a food web.

Mercury cycling: Transfer of mercury across environmental compartments such as the atmosphere, soils, water, sediment, and biota, and associated alteration of mercury's chemical form.

Mercury indicators: Environmental measurements that can be compared across time and space to understand changes in mercury exposure, concentration, and ecological effects.

Mercury methylation: Transformation of oxidized forms of mercury by microorganisms under oxygen-poor conditions, forming highly toxic methylmercury (MeHg⁺).

Mercury speciation: Different chemical forms of mercury in air, soil, water, and biota, including elemental mercury (Hg⁰), reactive gaseous mercury (RGM), particulate mercury (Hg-P), and methylmercury (MeHg⁺), that exhibit different behaviors in the environment.

Nested sampling design: Data-gathering strategy in which each type of measurement is made for only a single level of the sampling scheme.

Probabilistic monitoring: Environmental survey in which a randomly selected subset of sites or features is measured and the resulting data are used to estimate actual environmental conditions.

Sampling protocols: A consistent set of procedures for gathering and managing data.

Site characterization: Information about geographic location, site properties, and current and historical sampling activities that can assist in evaluating potential mercury monitoring sites.

Source-receptor relationships: Characterization of principal mercury sources that influence atmospheric mercury deposition to specific locations.

Spatial extrapolation: Projection of data from measured locations to estimate environmental conditions at nonmeasured locations or at larger scales using statistical techniques.

Total Maximum Daily Loads: The calculated maximum amount of a pollutant that a water body can receive from all point, nonpoint, and natural background sources and still meet water quality standards.



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