Atmospheric Environment 85 (2014) 109–122

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

A Great Lakes Atmospheric Mercury Monitoring network: Evaluation and design☆

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HIGHLIGHTS

- A Great Lakes Atmospheric Mercury Monitoring network is needed.
- A network of 21 sites is geographically representative and uniformly distributed.
- The network design is based on a scientific evaluation of mercury monitoring and emissions data.
- The network is a framework for regional collaboration on wet and dry mercury deposition monitoring.

ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form
19 November 2013
Accepted 20 November 2013

Keywords:
Mercury
Great Lakes
Mercury deposition
Atmospheric mercury
Mercury emissions
Mercury network

ABSTRACT

As many as 51 mercury (Hg) wet-deposition-monitoring sites from 4 networks were operated in 8 USA states and Ontario, Canada in the North American Great Lakes Region from 1996 to 2010. By 2013, 20 of those sites were no longer in operation and approximately half the geographic area of the Region was represented by a single Hg-monitoring site. In response, a Great Lakes Atmospheric Mercury Monitoring (GLAMM) network is needed as a framework for regional collaboration in Hg-deposition monitoring. The purpose of the GLAMM network is to detect changes in regional atmospheric Hg deposition related to changes in Hg emissions. An optimized design for the network was determined to be a minimum of 21 sites in a representative and approximately uniform geographic distribution. A majority of the active and historic Hg-monitoring sites in the Great Lakes Region are part of the National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN) in North America and the GLAMM network is planned to be part of the MDN.

To determine an optimized network design, active and historic Hg-monitoring sites in the Great Lakes Region were evaluated with a rating system of 21 factors that included characteristics of the monitoring locations and interpretations of Hg data. Monitoring sites were rated according to the number of Hg emissions sources and annual Hg emissions in a geographic polygon centered on each site. Hg-monitoring data from the sites were analyzed for long-term averages in weekly Hg concentrations in precipitation and weekly Hg-wet deposition, and on significant temporal trends in Hg concentrations and Hg deposition. A cluster analysis method was used to group sites with similar variability in their Hg data in order to identify sites that were unique for explaining Hg data variability in the Region. The network design included locations in protected natural areas, urban areas, Great Lakes watersheds, and in proximity to areas with a high density of annual Hg emissions and areas with high average weekly Hg wet deposition. In a statistical analysis, relatively strong, positive correlations in the wet deposition of Hg and sulfate were shown for co-located NADP Hg-monitoring and acid-rain monitoring sites in the Region. This finding indicated that efficiency in regional Hg monitoring can be improved by adding new Hg monitoring to existing NADP acid-rain monitoring sites.

Implementation of the GLAMM network design will require Hg-wet-deposition monitoring to be: (a) continued at 12 MDN sites active in 2013 and (b) restarted or added at 9 NADP sites where it is absent in

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1352-2310/$ – see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.atmosenv.2013.11.050

2013. Ongoing discussions between the states in the Great Lakes Region, the Lake Michigan Air Directors Consortium (a regional planning entity), the NADP, the U.S. Environmental Protection Agency, and the U.S. Geological Survey are needed for coordinating the GLAMM network.

1. Introduction

1.1. Mercury in the environment

Mercury (Hg) is a health threat to humans and wildlife because methylmercury (MeHg) bioaccumulates and increases in concentration in food webs. MeHg exposure can result in adverse neurological, cardiovascular, and reproductive effects in humans (Mergler et al., 2007). Developing infants and children are most susceptible to the harmful effects of MeHg, but adults have been affected by MeHg poisoning too (National Research Council, 2000). Neurological development and reproduction in wildlife can be damaged by MeHg exposure (Scheuhammer et al., 2007). MeHg concentrations are highest at top levels in the aquatic food web, so humans, wild mammals, and birds who consume fish risk exposure to harmful levels of MeHg. Public health agencies have issued advisories that warn about consumption of freshwater and marine fish because of risks from Hg (U.S. Environmental Protection Agency, 2011a).

Most of the Hg in aquatic ecosystems comes from deposition of atmospheric Hg (Lindberg et al., 2007). Important anthropogenic sources of atmospheric Hg include emissions from coal-fired power plants, industrial boilers, chlor-alkali plants, metals production, waste incinerators, and cement kilns. In 2010–2011, the U.S. Environmental Protection Agency promulgated regulations to reduce the emissions of Hg and other toxic pollutants from power plants and cement kilns (U.S. Environmental Protection Agency, 2010, 2011b), adding to regulations affecting Hg emissions from other sources (summary, U.S. Environmental Protection Agency, 2012a). An expected outcome of these regulations is that reduced Hg emissions will lead to reduced Hg levels in food webs and fewer fish consumption advisories for Hg in the future (Munthe et al., 2007).

1.2. Hg in the Great Lakes Region

The geographic focus of this paper is the North American Great Lakes Region; (hereafter, "Region"), defined as the eight USA states (Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, and New York) and the province of Ontario, Canada that border at least one of the five Great Lakes. Atmospheric Hg deposition in the Region has contributed to levels of MeHg in food webs that can harm humans and wildlife (Great Lakes Regional Collaboration, 2010). Public health advisories have been issued for the eight USA states and Ontario, warning about frequency of fish consumption because of risks from Hg (Ontario Ministry of the Environment, 2011; U.S. Environmental Protection Agency, 2011a). The average Hg concentrations in at least six species of frequently consumed fish from inland water bodies in the Region exceed the human health criterion, as summarized by Evers et al. (2011).

Substantial Hg emissions reductions are required by 2015, based on federal regulations in the USA (U.S. Environmental Protection Agency, 2012a) and rules for some states in the Region—Illinois, Michigan, Minnesota, New York, and Wisconsin (Illinois Environmental Protection Agency, 2007; Michigan Department of Environmental Quality, 2009; Minnesota Pollution Control Agency, 2006; New York Department of Environmental Conservation, 2012; Wisconsin Department of Natural Resources, 2008). Ontario implemented Hg emissions reduction standards in 2010 (Ontario Ministry of Environment, 2008). In addition, the Great Lakes mercury emission reduction strategy (Great Lakes Regional Collaboration, 2010), adopted 34 recommendations for regulatory and voluntary actions primarily aimed at reducing long-term Hg emissions and atmospheric Hg deposition in the Region.

Further reductions in the emissions of atmospheric Hg in the Region can be expected in the near future, but not because of emissions controls alone. Some coal-fired units at power plants of electric utilities and independent power producers will be retired for various reasons. Our analysis indicates 89 coal-fired units in 39 cities in the 8 USA states in the Region will retire during 2010 through 2019, with the majority (86 percent), to be retired before 2014. These units have a combined generation capacity of 11,411 MW, which is approximately 11% of the total coal-fired capacity in these states. The retiring units represent between 1.2% (Wisconsin) and 20.9% (Ohio) of the coal-fired capacity in each

Table 1
Summary of coal-fired energy generating units in the Great Lakes Region USA states to be retired, 2010–2019 [retired, actually retired or planned for retirement; MW, generating capacity in megawatts].

State	Number of units[a]	Number of cities[a]	Retired coal-fired capacity[a,b] (MW)	State coal-fired capacity in 2010[c] (MW)	Retired capacity share of state capacity (percent)	Coal-fired share of total state capacity[d] (percent)
Indiana	15	7	1942	19,097	10.2	69.1
Illinois	20	8	2670	15,551	17.2	35.2
Michigan	6	3	506	11,531	4.4	38.7
Minnesota	4	2	423	4789	8.8	32.5
New York	2	2	192	2781	6.9	7.1
Ohio	31	11	4465	21,361	20.9	64.6
Pennsylvania	6	4	1118	18,481	6.0	40.6
Wisconsin	5	2	95	8064	1.2	45.2
Great Lakes	89	39	11,411	101,655	11.2	

[a] Information summarized from Edison Electric Institute (2011).
[b] Retired capacity is the sum of generation capacity for all coal-fired units in a state to be retired.
[c] State capacity is the sum of coal-fired energy generation capacity from electric utilities and independent power production in a state in 2010 (U.S. Energy Information Administration, 2012).
[d] Coal-fired share is percentage of total state energy generation capacity from all fuel sources including renewables (U.S. Energy Information Administration, 2012).