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Mercury policy in the Great Lakes states: past successes and future opportunities

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Abstract While mercury (Hg) releases to air and water within the Great Lakes states have declined significantly, concentrations of mercury in fish remain a cause for concern regarding human and ecosystem health in the Great Lakes Basin. This paper assesses the priority that Hg source reduction ought to have in relation to some other environmental concerns, and explores the relative costs of various Hg reduction policies. Long-range transport of atmospheric mercury creates a collective action problem for states, since most of the mercury emitted within any given state deposits outside that state's borders, and since most of the mercury deposited within a state originated outside that state. This paper discusses some of the mechanisms that policy makers in the Great Lakes states employed to get beyond the collective action problem, including: providing an example for others to follow; using cross-jurisdiction cooperation to leverage the benefits of leadership on Hg reduction and control; and, promoting voluntary actions. Recommendations for future opportunities include: focusing reduction efforts on sources with the highest total mass of emissions rather than solely focusing on reduction of local deposition and utilizing all tools available in the clean air and clean water acts.

Keywords Mercury · Policy · Great Lakes · Environmental cost-effectiveness

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Overview of the mercury problem

Methylmercury (MeHg) is a potent neurotoxicant that may impair brain function and adversely affect neurological development in children, especially when exposure occurs in utero. Exposure to MeHg may also have negative cardiovascular health effects. The exposure route of greatest concern is the consumption of fish contaminated with MeHg. Hg can be converted to MeHg in aquatic ecosystems; as a result of bioaccumulation of MeHg through the aquatic food web, higher trophic level fish can be contaminated MeHg that pose health risks to fish consumers (Mergler et al. 2007). Air deposition is the primary input of Hg to most water bodies in North America, including the Great Lakes (Fitzgerald et al. 1998; Harris et al. 2007). In the places where air deposition is the primary Hg input, current knowledge is consistent with the expectation that changes in air deposition will produce roughly proportional changes in MeHg levels in fish, although proportional response has not been clearly demonstrated across different ecosystems (Munthe et al. 2007).

An estimated one-third to one-half of atmospheric Hg deposition cannot be controlled because it results from Hg naturally present in the atmosphere (Lamborg et al. 2002; Mason and Sheu 2002; Seigneur et al. 2004). The remaining one-half to two-thirds results from human activity, including releases caused by deliberate production and use of Hg in products and industrial processes, and releases caused by the use of raw materials such as fossil fuels, metal ores and limestone that naturally contain small concentrations of Hg.

All of the Great Lakes states have issued state-wide fish consumption advisories for MeHg. The Great Lakes themselves are also under fish consumption advisories due to elevated MeHg concentrations in fish (U.S. EPA 2007).

How big a priority is the Hg issue in the Great Lakes?

Elevated Hg contamination of fish imposes costs on society, not only from the effects of consumption of contaminated fish on IQ and other neurodevelopmental endpoints, but also from lost nutritional value from fish not consumed, decreased tourism related to recreational fishing, and a poorer outdoor recreation experience. In addition, Hg contamination results in costs on society by damaging the health of wildlife and ecological systems and, potentially, harming human cardiovascular health. Economic assessments have attempted to quantify the costs of mercury, focusing primarily on its impact on IQ. Even studies that limit themselves to assessing IQ impacts arrive at significantly varying results, driven primarily by the use of differing models of the dose–response relationship. Models that assume a threshold of exposure (measured in mg of MeHg consumption per kg of body weight per day) below which there are no effects estimate a lower cost of MeHg contamination than models that assume that there is no effects threshold and that even very low exposures have health consequences, albeit small ones. U.S. EPA's estimate of the benefits of reducing Hg emissions from coal-fired power plants is four times as high when no threshold is assumed, in comparison with the estimate using U.S. EPA's reference dose threshold (U.S. EPA 2005c). Moreover, it is not certain whether estimates of the neurological health benefits of reduced Hg exposure fully capture all of the benefits; these estimates are derived based on increased lifetime earnings associated with higher IQs that are expected to result from lower Hg exposure. Such estimates do not capture other potential societal consequences of neurotoxicant exposure that are more difficult to quantify, such as possible increases in violent behavior that may be associated with reduced IQ and diminished attention span. Carpenter and Nevin (2010) reviewed evidence that childhood exposures to chemicals that alter brain development could be an important contributor to violence and anti-social behavior throughout life. The evidence is persuasive that lead (Pb) exposure affects characteristics that correlate with a tendency to violence-reduced IQ, diminished attention span, and antisocial behavior. The authors note that exposure to other pollutants, including MeHg, also correlate with reduced IQ and attention span. These findings indicate that evaluating the neurological impacts of Hg exposure entirely through an assessment of lost earnings resulting from diminished IQ may leave out important additional social and personal impacts from reduced neurological performance (Carpenter and Nevin 2010). Moreover, most estimates of Hg cost do not capture the cultural, economic and health losses that can result from reductions in fishing and fish consumption motivated by a desire to reduce Hg exposure.

The cardiovascular health benefits of reduced Hg exposure are potentially of much higher value than the neurological health benefits, because of the higher economic value placed on prevention of deaths from cardiovascular disease in comparison with the value placed on avoiding small decrements in IQ, even in a much larger number of cases (Rice et al. 2010). However, the evidence that MeHg exposure has a cardiovascular health impact is mixed. A panel of nine expert reviewers convened by U.S. EPA reviewed the epidemiological evidence of a direct link between MeHg exposure and acute myocardial infarction (MI) and between MeHg exposure and intermediate impacts that contribute to MI risk. They found that there was sufficient evidence of this association to support the inclusion of MI in future assessments of the health benefits of mercury reduction (Roman et al. 2011). However, since the completion of this review of the evidence, the largest study to date of the impacts of MeHg exposure on the cardiovascular health of adult fish consumers found no impact (Mozaffarian et al. 2011).

Moreover, most economic valuation studies have focused on human health impacts, and have not addressed wildlife or ecosystem impacts. As a result, these studies tend to underestimate the damages caused by Hg. An exception is Hagen et al. (1999), who included wildlife impacts in a study of the willingness to pay by Minnesota residents for an Hg emissions reduction program. The authors did not separately value health benefits and wildlife/ecosystem benefits, so the value of the program cannot be divided between human and wildlife/ecosystem impacts.

To put in perspective the importance of Hg exposures and to facilitate comparison with other environmental priorities, Table 1 shows various estimates of the cost of IQ impacts from MeHg exposure expressed as a share of gross domestic product (GDP), and compares these costs to estimated costs of some other environmental issues. None of the Hg cost estimates include impacts to wildlife and ecosystems, to neurological health endpoints other than IQ, to cardiovascular health, or to costs of impaired recreational fishing opportunities. Thus, these assessments are likely to underestimate the true potential range of costs.

Table 1 Estimated costs of mercury pollution, compared with estimated costs of other pollutants

Pollutant	Share of GDP (%)	Geographic scope	Effects considered	Study
Hg	0.005	Global	IQ	Sundseth et al. (2010)
	0.03–0.2	U.S.	IQ	Rice and Hammitt (2005)
	0.02–0.4	U.S.	IQ	Trasande et al. (2005)
Pb	0.5	U.S.	IQ	Landrigan et al. (2002)
Air pollution	2.8	Germany	Respiratory and cardiovascular	Pervin et al. (2008)
	4.4	Italy		
	3.9	United Kingdom		
	3.4	Singapore		
	1.0	Jakarta		
Greenhouse gases	5–20	Global	Future impacts of climate change	Stern (2006)

Nonetheless, the range of these estimates is large—from 0.005 to 0.4% of GDP. Despite the uncertainties, and the possibility that these estimates may not be fully comparable in some ways, these estimates help frame a discussion of the priority that ought to be placed on reducing Hg exposures. First, even the lower end of the range of Hg cost estimates represents a significant cost imposed by a single pollutant, and would justify large expenditures to abate. At the higher end of the range of estimated costs, MeHg may impose neurological costs equivalent to those imposed by childhood Pb poisoning (Landrigan et al. 2002). Second, monetizing the estimated damages of these different pollutants allows us to make these comparisons, even among pollutants that have very different characteristics. For instance, MeHg is a single pollutant having primarily long-term neurological effects, while air pollution is a mix of pollutants having primarily acute respiratory effects. For mercury and air pollution, the biggest concerns are current human health effects, while for climate change the concerns are an anticipated future set of disruptions of uncertain magnitude to a broad variety of ecological, economic, and cultural systems. Reducing these impacts to monetary costs grossly simplifies these issues, but has the benefit of giving us a metric with which to make preliminary evaluations of the relative importance of different environmental priorities. Based on this comparison, the estimated costs of MeHg neurological health effects appears to be lower than costs estimated for current damages imposed by ozone and particulate air pollution (Pervin et al. 2008) or projected for future costs of climate change (Stern 2006).

While it is difficult to extrapolate from these global and national estimates of the damages imposed by Hg to the Great Lakes, it is clear that Hg is a significant problem in the region. All eight of the US Great Lakes states have statewide fish consumption advisories for MeHg. Moreover, while the Great Lakes are a relatively small commercial fishery in comparison with marine fisheries, the Great Lakes Basin is an important center for recreational and tribal fishing (Madsen et al. 2008). While the Great Lakes states have 27% of the U.S. population, they have 33% of recreational vessel registration nationwide, 31% of resident and non-resident anglers, and 29% of angler days spent fishing (United States Department of the Interior, Fish and Wildlife Service, and the United States Department of Commerce, United States Census Bureau 2006; United States Department of Homeland Security, U.S. Coast Guard Office of auxiliary and boating safety 2009).

Given these factors, it seems appropriate that Hg has been identified as a high priority for the Great Lakes region. The 1985 Report of the Great Lakes Water Quality Board identified 11 critical pollutants, including Hg. While some of the other pollutants have become a lesser priority as they were phased out of commerce, Hg continues to be a focus of several Lakewide Management Plans, the Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin and now, the Great Lakes Regional Collaboration.

Valuing costs and benefits of reducing Hg pollution

The question of whether the costs of particular Hg reduction policies are justified by the benefits is theoretically straightforward, but difficult to address in practice. In theory, we should be able to compare the marginal costs of various techniques for reducing environmental releases of Hg to marginal benefits of reduced Hg exposure; if the benefits of reduced exposure exceed the costs of control, the controls are justified. In practice, however, we rarely have sufficient knowledge to make such comparisons with confidence. The current costs of reduction techniques can usually be estimated fairly reliably, although it can be difficult to predict how costs will change as technologies and practices improve (Harrington et al. 1999). Some reduction techniques will produce ancillary benefits, such as reductions in pollutants other than Hg that are not always factored into a cost-benefit analysis. Other reduction approaches may produce environmental costs, such as the use of alternative materials that are also toxic. The benefits of Hg reduction are more difficult to quantify than the costs because of the uncertainties about health effects discussed above. Moreover, the impact of a given amount of emissions reduction cannot always be easily translated into predicted changes in exposures.

Some published cost-benefit analyses calculate the benefits of U.S. emission reductions through modeling the impacts on fish MeHg levels in specific areas. This approach can provide a careful assessment of the impact of reductions on the exposures that the reductions will most directly impact, but it is likely to understate overall costs because it does not place a value on the small but widespread impact that reductions have on global mercury levels. For instance, EPA modeled the impact of emission reductions from electric utilities on freshwater fish, while Rice and Hammitt (2005) modeled the impact on freshwater fish and marine fish in coastal U.S. waters. Neither approach considered the benefit of U.S. emissions reductions to U.S. consumers of fish caught beyond U.S. waters, nor did these studies consider the benefits of U.S. emissions reductions for non-U.S. fish consumers. Another cost-benefit approach is to estimate the average impact of emission reductions, regardless of where they occur, based on global exposures to MeHg. Spadaro and Rabl (2008) estimated that a kilogram of Hg emissions has a marginal neurological health cost of $1,500–3,400/kg based on an assessment of impacts of global Hg exposures on IQ. The lower estimate assumes that MeHg exposure has an effects threshold of 6.7 μg/person/day; the higher estimate assumes no threshold. These estimates are based on an approach that treats all Hg emissions as entering the global Hg cycle, eliminating the modeling task of connecting specific emissions with deposition to particular areas. This global approach has the advantage of attempting to capture the benefits of policies reducing primarily emissions of Hg(0) that may have little impact on a local regional basis but that contribute to the global pool of atmospheric Hg. However, this global approach may underestimate the benefits of emission reductions that reduce exposures primarily in wealthier countries, since benefit calculations rely on estimates of reduced income resulting from IQ losses caused by Hg exposure and per capita incomes are higher in advanced economies than the global average. Spadaro and Rabl (2008) estimate the global IQ benefits of reducing U.S. emissions at $4,380–11,200, based on an estimate that 60 percent of these emissions are deposited on U.S. soil; this range would be higher for sources depositing more than 60 percent of their emissions within the United States and lower for sources that deposit less mercury within the United States. They noted, however, that actual neurological health benefits of reductions could be four times lower or higher than estimated, and that inclusion of cardiovascular health benefits could significantly increase the estimated reduction benefits (Spadaro and Rabl 2008).

Reputable studies come to differing conclusions regarding the costs of Hg exposure, the benefits of Hg reduction, and whether or not particular Hg abatement efforts are economically justified. Swain et al. (2007) reviewed various attempts to quantify the costs and benefits of reducing U.S. emissions from power plants. They found that some studies estimated costs greatly exceeding benefits; for instance, Gayer and Hahn (2005) estimated that a power plant emissions cap of 15 tons would cost $3.4–to 5.5 billion to implement, but achieve benefits worth only $50–150 million. However, Palmer et al. 2005 estimated that the costs and benefits of the same policy would be roughly equal, with costs of $3.4 billion and benefits of $3.5 billion. A number of factors influence the outcomes of these studies. Gayer and Hahn (2005) used benefit estimates generated by the U.S. EPA, which include IQ impacts only, and which evaluate impacts only due to consumption of freshwater fish. Palmer et al. (2005) used benefit estimates generated by Rice and Hammitt (2005), which include both IQ and cardiovascular impacts caused by reductions in MeHg concentration of marine and freshwater fish. The biggest differences are caused by whether or not cardiovascular impacts as well as IQ impacts are considered (Swain et al. 2007). U.S. EPA's analysis of its recent proposal to regulate hazardous air pollutant emissions from coal-fired power plants estimated costs of $10.9 billion, with benefits exceeding these costs by a ratio of between 5 to 1 and 13 to 1. Most of these benefits, however, related to reductions in fine particulates resulting from hazardous air pollutant controls, rather than from mercury reductions themselves. U.S. EPA's analysis of the mercury costs and benefits alone show annual costs of $2.3 billion and benefits of only $0.45 to $5.9 million. However, these estimated benefits include only the IQ impacts from U.S. freshwater fish consumption (U.S. EPA 2011a).

Emissions controls on power plants are not the only way to reduce mercury emissions. Table 2 shows the estimated costs of a range of different approaches to reducing atmospheric mercury emissions, including waste management approaches as well as emissions control techniques for power plants and other sources. A range of estimates is shown, with lower cost estimates for waste management approaches based on the assumption that eventually all of the mercury contained in mercury-containing products would be emitted to the atmosphere if they were disposed of improperly, and that all of these emissions can be prevented by proper management of disposal. The higher cost estimates assume that only a fraction of the improperly-disposed mercury would have been emitted to the atmosphere, with the fraction reduced through proper management calculated using the mercury flow model

Table 2 Costs of reducing Hg emissions to air by 1 kg, various approaches

	Low cost estimate[a]	High cost estimate[a]	Notes	Sources
Hg waste management approaches				
Collect Hg(0) through HHW program	$8	$840	High cost assumes that collection prevents emissions of one percent of collected Hg. Oregon DEQ estimates that elemental mercury collection costs $4 per pound collected, or $8.40/kg	Lane county lamp recycling coalition (2006), Table 6–11
Collect thermostats through thermostat recycling corporation	$313	$6,267	High cost assumes that collection prevents emissions of five percent of collected Hg. $1.41 per thermostat, under TRC thermostat recycling program	Mercury policy project (2010)
Collect Hg-containing devices through HHW program	$600	$12,000	High cost assumes that collection prevents emissions of five percent of collected Hg. Oregon DEQ estimates that HHW Hg collection costs $565/kg collected ($269 per lb). This cost represents only contract costs for local governments. Add roughly 5% for program administration and advertising, yielding $600 per kg collected.	Lane county lamp recycling coalition (2006), Table 6–11
Collect auto Hg switches	$2,500	$2,660	High cost assumes that collection prevents emissions of 94 percent of collected Hg. $3/switch.	New Jersey Department of environmental protection (2004)
Collect compact fluorescent light bulbs	$80,000	$2,727,273	High cost assumes that collection prevents emissions of 11 percent of collected Hg. $0.40–$1.50 per lamp collected	Maine Department of environmental protection (2010)
Emissions control cost estimates				
Portland cement	$12,997			U.S. EPA (2010b)
Sewage sludge incinerators	$13,228		For activated carbon injection	U.S. EPA (2010c)
Gold mines	$13,230		In this rulemaking, EPA rejected more stringent controls that would have cost $92,400/kg	U.S. EPA (2011b), 9496
Coal-fired utility boilers	$21,000	$85,000	Low cost based on DOE estimate that costs of activated carbon injection can "dip below" $21,000/kg of Hg from coal-fired power plants. High cost based on U.S. EPA estimates in the proposed utility air toxics rule that assume that 10% of the costs of dry fluid gas desulfurization and fabric filters and 51% of the cost of costs of activated carbon injection are allocated to Hg control (with the remainder allocated to fine particulate control)	Feeley et al. (2008) U.S. EPA (2011a)

[a] Low cost estimates assume that collection of Hg in waste management program prevents emissions of 100% of the collected Hg. High cost estimates use the mercury product flow model in Cain et al. (2007) to estimate the difference between Hg emissions when wastes are properly managed and when they are improperly managed

described by Cain et al. (2007). In a cost-benefit analysis, most of the reduction approaches in Table 2 could be classified as either cost-effective or cost-ineffective, depending on whether the high or low cost estimates are used and which estimates of reduction benefit are utilized.

We present Table 2 not for the purpose of cost-benefit analysis, but in order to compare the costs of different reduction approaches to each other. Given the uncertainties involved, cost estimates within an order of magnitude of each other should not be considered to be substantially different. Given this caveat, we can conclude that collection of elemental mercury appears to be more cost-effective than other approaches considered, while collection of compact fluorescent lamps (CFLs) is orders of magnitude more expensive than the other approaches. This sort of comparative cost data has not typically been used in setting mercury reduction policy. In the future, such analysis can be used to prioritize mercury reduction efforts, particularly for limited state and local government funds.

We have not developed a cost-benefit analysis specifically for the Great Lakes states, but we believe that because of the vulnerability of many watersheds in this region to Hg contamination and the great importance of the Great Lakes water resources that Hg emission reduction has particular importance for the Great Lakes states.

Current policy approaches for reducing Hg releases within the Great Lakes states

Hg is an environmental problem at the local, regional and global scales. In the Great Lakes region, control of direct water discharges and of the air emissions sources with the largest local impact has meant that increasingly, Hg deposition to the Great Lakes states originates in emissions outside of the region (U.S. EPA 2010a). Moreover, while reducing the remaining releases of Hg within the Great Lakes states will have some impact on Hg deposition to the Great Lakes states, much of the benefit of these reductions will occur outside of the Great Lakes states, through small, perhaps imperceptible, reductions in global Hg deposition. Therefore, it is increasingly difficult to justify the costs of some Hg reductions in the Great Lakes states based solely on their direct benefit within the Great Lakes states. This situation is particularly evident for strategies that would reduce emissions primarily of Hg(0), such as banning the sale of Hg-containing products, although there are direct benefits from reduced Hg(0) exposures resulting from indoor spills.

A similar calculus applies in other regions of the North America, and globally. Thus, Hg increasingly presents a free-rider problem in which every state can benefit from the Hg emission reduction efforts of others, but no state will necessarily benefit sufficiently from its own reduction efforts to justify the costs. The danger in such a situation is that even though the benefits of collective action would exceed the costs, free-riding by some will prevent collective action from occurring. Nonetheless, some Great Lakes states have succeeded in pursuing leadership on Hg reduction, and have chosen to implement reduction strategies even where the benefits would be widely dispersed and not noticeable locally.

This section will discuss the policy approaches that have allowed the Great Lakes states to at least partly escape the free-rider problem and pursue Hg reduction policies based on the expectation that these policies would ultimately benefit the Great Lakes region. These policies include: providing a good example for others to follow; using cross-jurisdiction cooperation within the Great Lakes and beyond to leverage the benefits of leadership on Hg reduction and control; and, promoting appropriate regulatory and voluntary action.

Providing a good example

The Great Lakes Region has played an important role in nationwide Hg reduction efforts; frequently, state or municipal action in the Great Lakes region has helped inform and support action in other regions and nationwide. In some cases, reduction efforts focused on sources with a large local impact, creating a large local benefit that was multiplied when other jurisdictions followed suit. For instance, in the 1990s, Minnesota and New York were leaders among states in setting mercury emissions standards for municipal and medical waste incinerators on incinerators, not only inspiring action by other states but also by the federal government (U.S. EPA 1995).

However, Great Lakes states have also taken mercury control actions whose benefits were more diffuse, and which primarily affected emissions of mercury transported beyond state boundaries. The Great Lakes states, along with the Northeast states, have shown particular leadership in identifying and reducing or eliminating Hg in consumer products. In some cases these efforts were motivated by concerns about direct inhalation exposures caused by these products. In other cases efforts were motivated by the significant contribution that Hg-containing product usage, breakage and disposal contribute to environmental Hg emissions (Cain et al. 2007). In many cases, actions by individual states or cities have helped trigger nationwide action.

In 1992, Minnesota was among the first states to begin to ban Hg in a variety of products and prohibit disposal of Hg and Hg products in solid waste. Early bans in 1992 through 1994 included the sale of toys games and apparel containing Hg. These product-related efforts extended beyond products that created a direct exposure concern to include products such as batteries and auto mercury switches, for which the primary issue was atmospheric mercury emissions. In 1993, Minnesota along with New Jersey and Arkansas banned the sale of mercuric oxide batteries and limited the Hg content of alkaline batteries. Federal law caught up with the states in 1996 (Sznopek and Goonan 2000). Building on these actions, all of the Northeast states and many others have adopted comprehensive mercury products legislation and regulations (Smith and Trip 2005).

Michigan's Mercury Pollution Prevention (M2P2) Task Force determined in 1995 that domestic automobile manufacturers were using more than nine metric tons of Hg(0) annually in convenience light switches (Michigan mercury pollution prevention task force 1996). The M2P2 Task Force secured a commitment from the domestic auto manufacturers to eliminate this use nationwide, a commitment eventually met in 2003.

In 2000, the city of Duluth, Minnesota became the first U.S. city to ban sales of Hg-containing fever thermometers, an example quickly followed by several other cities, and subsequently by states (Healthcare without Harm 2010). These local bans and the awareness campaigns associated with them led quickly to a collapse in Hg fever thermometer sales and termination of production and marketing efforts for these products.

More recently, Illinois, Wisconsin, Michigan, Minnesota, Pennsylvania, and New York were among the states that promulgated rules controlling Hg emissions from coal-fired power plants, in advance of federal requirements. Ohio and Indiana did not follow suit, but U.S. EPA has proposed a maximum available control technology

(MACT) standard for these sources, and is scheduled to finalize the regulation before the end of 2011. State rules developed in advance of the federal action helped demonstrate that control technologies are available and that they function well at power plants. States in the Great Lakes region were also among the first in the country to develop comprehensive, multimedia Hg reduction strategies. Minnesota developed its first Hg reduction strategy in 1994, followed up by a comprehensive, multi-media strategy in 1999 (MPCA, Mercury Task Force 1994). Michigan developed a comprehensive Hg pollution prevention (P2) strategy in 1996 (Michigan mercury pollution prevention task force 1996).

All of these efforts have had multiplier effects, helping to stimulate actions in other states and regions and nationally. Action to eliminate Hg use in specific products has had widespread impact, because product bans in one or a few states provide a market signal to shift away from the production and sale of Hg-containing products nationally and even internationally. This experience with mercury provides an important lesson for policy makers; it is possible to overcome environmental collective action problems through well-publicized actions initiated by states willing to set a good example. In some cases, such as product bans, actions by a few states are sufficient to transform the market and achieve widespread results. In other cases, such as emissions control requirements, action by individual states leads to widespread results by paving the way for federal actions.

Cross-jurisdiction cooperation within the Great Lakes

Along with these important actions by individual Great Lakes states, the Great Lakes region has acted collectively to address Hg issues and to encourage more widespread adoption of successful reduction approaches. Under the Great Lakes Water Quality Agreement, Environment Canada and the U.S. EPA signed the Great Lakes Binational Toxics Strategy in 1997, providing a framework for actions to reduce and “virtually eliminate” anthropogenic inputs to the Great Lakes of persistent, bioaccumulative, and toxic substances, including Hg. This Strategy contained the first specific pollution reduction targets to be set jointly by these two countries, including 50 percent reduction challenges for Hg emissions and Hg use in the United States. Under the Strategy, established an Hg reduction workgroup was established consisting of federal, state, provincial and local government staff, as well as stakeholders from industry and environmental groups. This workgroup followed a four-step process of developing information about Hg in the Great Lakes environment, reviewing existing programs and regulations, identifying opportunities for cost-effective reductions, and implementing actions.

The Binational Toxics Strategy Mercury Workgroup remained active through 2008 and helped coordinate efforts to reduce Hg use, to promote dental amalgam waste best management practices for dental offices, and to promote improved management of automobile Hg switches. The Binational Toxics Strategy provided state and local government leaders on Hg reduction with a forum to share their success stories with other governments within the Great Lakes region and to encourage others to follow their example. This effort also allowed for beneficial cross-jurisdiction cooperation with Canadian stakeholders. This initiative also helped inform and spur the development and adoption of the bi-national New England Governors and Eastern Canadian Premiers Mercury Action Plan in 1998.

The Great Lakes-wide Hg coordination efforts are now being addressed via the Great Lakes Regional Collaboration (GLRC), a process begun under a Presidential Order (13340) in 2004. Key members of this national cooperative partnership include the Council of Great Lakes Governors, Great Lakes and St. Lawrence Cities Initiative, Great Lakes Congressional Task Force, Great Lakes Indian Fish and Wildlife Commission, and the U.S. EPA Great Lakes National Program Office. Under the GLRC, the Great Lakes states are collectively holding themselves to high standards for Hg reduction programs. In June 2008, the GLRC finalized its first basin-wide Hg reduction strategy, the *Great Lakes Mercury in Products Phase-Down Strategy*, which includes 55 recommendations for state regulatory and voluntary efforts to reduce the use of Hg in products, where practical, and to improve the management of Hg-containing product waste (GLRC 2008). In 2010, the GLRC developed the *GLRC Mercury Emissions Reduction Strategy*, a basin-wide strategy that includes 34 recommendations to require Hg best available technology controls on a broader range of sources in the Great Lakes Region (GLRC 2010).

Cross-jurisdiction cooperation beyond the Great Lakes region

In addition to Regional cooperation, the Great Lakes states are also vigorous participants in broader national and international collaboration to address Hg. Recognizing the need to collaborate in order to effectively reduce Hg in the environment, individual state environmental organizations and their national air, water and waste associations have joined together to share Hg-related technical and policy information and to advocate for effective national Hg policies and programs. This coalition, formed under the leadership of the Environmental Council of the States (ECOS) in 2001, is called the Quicksilver Caucus (QSC).

The QSC consists of staff and leaders from these state associations and agencies who are active in Hg issues, including most states in the Great Lakes region. The QSC facilitates work between states and collaborates with the U.S. EPA on Hg reduction policies. The QSC's long-term goal is that state, federal, and international actions result in net Hg reductions to the environment (ECOS 2005).

In 2003, the environment ministers from nations around the world declared that international action was warranted to address Hg and established a Mercury Program within the United Nations Environment Programme (UNEP). Further, in 2009 UNEP voted to pursue a binding international treaty to reduce Hg. Negotiations commenced in June 2010 and are expected to be completed in 2013. The QSC has established itself as a key stakeholder of the U.S. Government and provides input and support to the U.S. negotiators. Meanwhile, the UNEP Mercury Program is working on building capacity among all nations to address Hg while also fostering partnerships to reduce Hg in key areas.

These efforts have the potential to lead to international adoption of some of the reduction approaches pioneered in the Great Lakes states. While it is not the role of the Great Lakes states to lead international efforts to reduce Hg, nor do they have the resources to do so, they do contribute in significant ways. State staff participates in UNEP partnerships, in particular in the Mercury-Containing Product Partnership. State staff, at the invitation of U.S. EPA, has served as technical advisors to selected countries, including Mexico and Taiwan, in developing Hg reduction initiatives. In addition, state staff has assisted the UNEP Mercury Programme in developing guidance documents and awareness raising activities for developing countries.

Promote voluntary action

In part because of the difficulty of requiring Hg reductions whose local impacts are difficult to quantify, the Great Lakes region has promoted voluntary action to reduce Hg as a supplement to regulatory approaches. Voluntary actions have had important benefits through they have had significantly less impact than regulatory actions. In some cases, voluntary approaches have been highly successful; in other cases they have been disappointing. Some voluntary efforts have been followed by state or national regulation that has required an entire sector to take actions that only some in the sector had implemented previously. Successful voluntary Hg reduction efforts in the Great Lakes states have focused on raising awareness about Hg and providing examples of actions that citizens can take to limit Hg uses and thereby releases, and similarly, working with businesses to reduce Hg and then providing those businesses with public recognition.

All of the Great Lakes states began working in various ways in the 1990s to promote public awareness of Hg. For instance, the Indiana Department of Environmental Management (IDEM) developed a formal "Mercury Awareness Program" to inform citizens about the Hg problem, describe household products that might contain Hg, and offer proper disposal opportunities for these products at facilities in all 92 counties. As a result of these efforts, IDEM collected 53 tons of Hg and Hg-containing items and debris from households and small businesses in 2007 (Indiana Department of Environmental Management 2008–2009). Increased public awareness of Hg, combined with convenient Hg collection through household hazardous waste programs, has resulted in significant Hg collections in all of the Great Lakes states.

The Great Lakes Binational Toxics Strategy included a "challenge" to industry to help achieve reductions of 50 percent in Hg use and Hg emissions nationwide. In response, the U.S. chlor-alkali industry, through the Chlorine Institute, committed to reducing its use of Hg by 50 percent between 1995 and 2005, a goal that it has greatly exceeded. The Chlorine Institute's Twelfth Annual Report to EPA shows a drop in total annual Hg use of 97 percent between 1995 and 2008, and a 94 percent reduction in Hg use per ton of chlorine used. Many of the practices promoted under this voluntary effort have since become regulatory requirements under U.S. EPA emissions control standards (U.S. EPA 2008).

The voluntary program Hospitals for a Healthy Environment (H2E) began under the Strategy as a partnership among the U.S. EPA, the American Hospital Association (AHA), the American Nurses Association, and Health Care without Harm. This partnership encouraged hospitals to eliminate the use and purchase of Hg-containing products such as measurement and control devices, and to properly dispose of Hg-containing products currently in health care facilities. In 2006, the successful H2E Program ended as the U.S. EPA's signature Hg reduction program for healthcare facilities, and became an independent, non-governmental organization that has continued to grow (Hospitals for a Healthy Environment 2010).

Michigan's M2P2 Task Force encouraged voluntary efforts as well, and succeeded in getting significant reduction commitments from automobile manufacturers, though there were delays in meeting these commitments. In 1995, General Motors Corporation, Ford Motor Company and the Chrysler Corporation sent letters to the M2P2 Chairman that committed to a goal of becoming Hg-free for convenience light switches by 1997, 1998 and 1997, respectively (Michigan mercury pollution prevention task force 1996).

Minnesota took a comprehensive approach to voluntary Hg reduction, inviting all emitters of more than 50 lb of Hg per year to enter into voluntary agreements to reduce Hg and submit periodic reports outlining their progress. A 2005 report by the Minnesota Pollution Control Agency (MPCA) found that voluntary agreements with electric utilities and the state's largest sewage treatment authority had achieved some reductions in emissions from coal-fired power plants and a sludge incinerator. However, the reductions achieved were fairly modest, equivalent to approximately three percent of 1990 emissions. Much more significant reductions had been achieved through state and federal regulatory requirements limiting the Hg content of paints, batteries and fungicides, and reducing emissions from waste incinerators. Voluntary agreements also led to research on emission controls at taconite facilities, to improvements in Hg waste management, and to increased public awareness. MPCA concluded that "achieving the reductions needed from all sectors will require additional voluntary and regulatory strategies" (MPCA 2005). Subsequently, MPCA determined that 93 percent reduction in Hg emissions statewide from 1990 levels would be needed to meet the requirements of the statewide Minnesota Hg total maximum daily load (TMDL), with reductions required in particular from the largest remaining sectors: coal-fired power plants and taconite production facilities. Section 303(d) of the Clean Water Act (CWA) requires states to evaluate their water bodies and determine if they meet water quality standards. The standards are set on a wide range of pollutants, including Hg, and water bodies that fail to meet standards are designated as Impaired Waters. To begin to address impaired waters, states are required to evaluate the sources of pollution, the reduction in the pollutant needed to meet water quality standards, and allowable levels of future pollution. This evaluation is called a TMDL and must be approved by the U.S. EPA. Minnesota involved stakeholders in TMDL implementation, securing significant reduction commitments from the taconite industry and other sectors. The MPCA has proposed rules to implement these commitments. For coal-fired power plants, Minnesota imposed a state-wide regulation, after extensive consultation with industry (MPCA 2010).

Future actions and opportunities

Focus reduction efforts on total mass of emissions

One potential approach to Hg reduction, which could be called the receptor-based approach, would be to evaluate the reductions necessary to meet water quality standards in water bodies in the Great Lakes states and/or inland lakes that do not meet health criteria. Modeling would be used to identify the dominant sources of Hg to these water bodies, and reduction efforts could be focused on these sources until water quality standards are met. If a government regulated Hg solely using a receptor-based approach, emissions of Hg(0) would be viewed as preferable to emissions of oxidized Hg, because oxided Hg is deposited much closer to emission sources, having a deposition velocity about 100 times faster than that of Hg(0) (Seigneur et al. 2004). Section 303 of the federal CWA would seem to mandate a receptor-based approach, through its requirement that states develop TMDLs for Hg-impaired water bodies.

A source-based approach can be used instead, or in addition to, the receptor-based approach (e.g. Minnesota's Hg policy). Unlike the receptor-based approach, the source-based approach addresses the total mass of Hg emitted, regardless of whether local impacts can be demonstrated, based on the principles that (a) as an element, Hg never decomposes, (b) all Hg emitted is deposited somewhere on the globe, (c) even when globally diluted, bioaccumulation of MeHg produces unacceptably high concentrations in fish, and (d) therefore, the goal of all governmental jurisdictions should be to reduce the mass of Hg emitted.

The federal Clean Air Act (CAA) takes primarily a source-based approach, requiring "maximum available control technology" (MACT) for the largest sources of hazardous air pollutants (HAPs), including Hg, within a sector. Imposition of these controls does not depend on a finding that a source is impacting a particular receptor. It should be noted that currently the definition of a major source of a HAP within section 112(a)(1) of the CAA is a source that emits 10 tons per year or more of any HAP or 25 tons per year or more of any combination of HAPs. To date, U.S. EPA has not exercised CAA provisions that would allows it to set lower thresholds for persistent and bioaccumulative pollutants, allowing many large sources to escape regulation. The receptor-based approach can be appealing for a number of reasons: in circumstances where a limited number of sources are causing water quality problems in a limited number of water bodies, a receptor-based approach focuses reduction efforts on the sources that have the largest impact on those water bodies. However, there are several conditions that can make a receptor-based approach less appealing, each of which applies to the problem of mercury reduction in the Great Lakes states. First, when the number of impaired water bodies is large, providing modeling and analysis for even a fraction of them would be an expensive task. Second, when the contamination problem results from a combination of many sources, including sources outside of the state or country, and none of these sources individually contribute more than a fraction of a percent of loadings to any particular water body, the receptor-based approach does not effectively focus reduction efforts. Third, if the ability to impose controls on any particular source depends on the showing of a significant contribution from that source to a particular water body, control requirements may be challenged on the basis that the single source is negligible.

Challenges are particularly likely if a large number of sources are potential contributors to loadings at the receptor. Thus, under some circumstances, a receptor-based approach can lead to a situation where no one source bears sufficient responsibility for Hg contamination to be reduced. Through a seemingly rational approach, an irrational result is produced. By contrast, a less selective approach of simply identifying sources above a given minimum size and reducing their Hg emissions to the extent possible may produce a better result, but only if this approach is adopted nationwide and even internationally.

The Great Lakes states have pursued, as a policy, primarily a source-based approach, with some elements of a receptor-based approach attempted in some cases. For instance, the Great Lakes Binational Toxics Strategy followed an approach of seeking "virtual elimination" of Hg releases to the Great Lakes Basin, focusing on finding opportunities to cost-effectively reduce sources regardless of whether they could be shown to have a large impact on the Great Lakes. Minnesota currently has a dual approach, evaluating new emission sources for local deposition, while maintaining a state-wide goal for reducing total mass of Hg emissions.

Available CAA tools

The GLRC Mercury Emissions Reduction Strategy (2010) includes two relevant recommendations: first, that EPA use the existing authority in section 112(a)(1) of the CAA to establish a major source category threshold for Hg lower than the existing threshold. This Strategy further states that the threshold for Hg and other HAPs "should be considerably lower due to their persistence, bioaccumulative nature and known toxicity. Based on current state programs the threshold for establishing major sources could range from 3 to 25 lb for Hg emissions." In other words, the states recommend that the U.S. EPA extend to additional sources, and smaller sources, the CAA approach of mandating controls on sources regardless of proven impact on receptors. There are still several sectors that are not effectively being addressed by the current implementation of the CAA, including Hg-product manufacturing, electric arc furnaces, sewage sludge dryers, crematories, recycling facilities, taconite and iron mining and other sources not yet adequately characterized.

Second, the strategy recommends to Great Lakes states that:

> All states should require best available control technology (BACT) for Hg emissions from new and modified air sources. States that do not currently have the authority to require BACT for new and modified air sources should consider legal changes that would provide such authority, considering a threshold of 10 lb or less of Hg per year.

Available CWA tools

While section 303(d) of the CWA would seem to promote a receptor-based approach to Hg control, the MPCA pioneered a creative state-wide TMDL approach to these requirements that complies with the law while in fact using a source-based approach. Minnesota prepared a state-wide TMDL which concluded a 93% reduction in deposition from 1990 levels is needed to meet fish MeHg targets. The MPCA worked with stakeholders to develop sector and source-specific reduction goals as well as interim and final timeframes for meeting the goals. While the ultimate goal of the TMDL is to reduce Hg inputs to impaired water bodies to safe levels, individual sources are addressed based on potential mass of Hg emissions reduction, without regard to receptor impacts. Once a TMDL is approved by the U.S. EPA, states are responsible for implementing measures to achieve the goals established in the TMDL. By applying the reduction goals to in-state emissions, Minnesota's TMDL established a final air emission goal of 789 lb per year, compared to approximately 3,400 lb per year of emissions in 2005.

Following the U.S. EPA's approval of Minnesota's TMDL seven states in the Northeastern U.S. have collectively prepared a regional Hg TMDL seeking 98% reductions from 1998 levels. New Jersey also prepared a statewide Hg TMDL; both the Northeastern states and New Jersey followed the example set by Minnesota. Michigan is currently in the process of developing their statewide TMDL as well, following the examples set by Minnesota and the Northeastern states. The Northeastern states have also petitioned the U.S. EPA to address Hg emissions in 11 upwind states (including five Great Lakes states) whose Hg emissions are transported to their region. As more of these regional issues are addressed, the prevalence of free-ridership will be reduced.

Conclusion

Considerable progress has been made within the Great Lakes states in reducing Hg use and emissions by utilizing various policy approaches. Opportunities still exist to further reduce Hg emissions and subsequent deposition by fully utilizing all the tools available in the CWA and the CAA. Activities should continue beyond the Great Lakes states and U.S. borders to adequately address the international impact of Hg on the nation's environment.

Policy makers who need to balance concern about mercury with other environmental priorities and with concerns about the costs to society of Hg control could benefit from some additional social-science research on the Hg problem. In particular, it would be useful to refine our understanding of the economic costs of Hg by evaluating the economic costs of known ecological impacts, such as the effects of MeHg on fish and wildlife reproduction. Economics research on this issue is lacking. Moreover, policy makers would benefit if future evaluations of the ecological and human health cost impacts of Hg assessed both the regional and global benefits of Hg emissions reductions. Such an approach would help clarify to policy makers that while they are rightly concerned with addressing MeHg fish concentrations in their own jurisdictions, that mercury emissions reductions have important benefits worldwide.

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