Appendix G:
Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain

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Methyl mercury is a developmental neurotoxicant. Exposure results principally from consumption by pregnant women of seafood contaminated by mercury from anthropogenic (70%) and natural (30%) sources. Throughout the 1990s, the U.S. Environmental Protection Agency (EPA) made steady progress in reducing mercury emissions from anthropogenic sources, especially from power plants, which account for 41% of anthropogenic emissions. However, the U.S. EPA recently proposed to slow this progress, citing high costs of pollution abatement. To put into perspective the costs of controlling emissions from American power plants, we have estimated the economic costs of methyl mercury toxicity attributable to mercury from these plants. We used an environmentally attributable fraction model and limited our analysis to the neurodevelopmental impacts—specifically loss of intelligence. Using national blood mercury prevalence data from the Centers for Disease Control and Prevention, we found that between 316,588 and 637,233 children each year have cord blood mercury levels > 5.8 μg/L, a level associated with loss of IQ. The resulting loss of intelligence causes diminished economic productivity that persists over the entire lifetime of these children. This lost productivity is the major cost of methyl mercury toxicity, and it amounts to $8.7 billion annually (range, $2.2–43.8 billion; all costs are in 2000 US$). Of this total, $1.3 billion (range, $0.1–6.5 billion) each year is attributable to mercury emissions from American power plants. This significant toll threatens the economic health and security of the United States and should be considered in the debate on mercury pollution controls. *Key words:* children's health, cognitive development, cord blood, electrical generation facilities, environmentally attributable fraction, fetal exposure, lost economic productivity, mercury, methyl mercury, power plants. *Environ Health Perspect* 113:590–596 (2005). doi:10.1289/ehp.7743 available via *http://dx.doi.org/* [Online 28 February 2005]

Mercury is a ubiquitous environmental toxicant (Goldman et al. 2001). It exists in three forms, each of which possesses different bioavailability and toxicity: the metallic element, inorganic salts, and organic compounds (methyl mercury, ethyl mercury, and phenyl mercury) (Franzblau 1994). Although volcanoes and other natural sources release some elemental mercury to the environment, anthropogenic emissions from coal-fired electric power generation facilities, chloralkali production, waste incineration, and other industrial activities now account for approximately 70% of the 5,500 metric tons of mercury that are released into the earth's atmosphere each year [United Nations Environmental Programme (UNEP) 2002]. Elemental mercury is readily aerosolized because of its low boiling point, and once airborne it can travel long distances to eventually deposit into soil and water. In the sediments of rivers, lakes, and the ocean, metallic mercury is transformed within microorganisms into methyl mercury (Guimaraes et al. 2000). This methyl mercury biomagnifies in the marine food chain to reach very high concentrations in predatory fish such as swordfish, tuna, king mackerel, and shark (Dietz et al. 2000; Gilmour and Riedel 2000; Mason et al. 1995; Neumann and Ward 1999). Consumption of contaminated fish is the major route of human exposure to methyl mercury.

The toxicity of methyl mercury to the developing brain was first recognized in the 1950s in Minamata, Japan, where consumption of fish with high concentrations of methyl mercury by pregnant women resulted in at least 30 cases of cerebral palsy in children; exposed women were affected minimally if at all (Harada 1968). A similar episode followed in 1972 in Iraq when the use of a methyl mercury fungicide led to poisoning in thousands of people (Bakir et al. 1973); again, infants and children were most profoundly affected (Amin-Zaki et al. 1974, 1979). The vulnerability of the developing brain to methyl mercury reflects the ability of lipophilic methyl mercury to cross the placenta and concentrate in the central nervous system (Campbell et al. 1992). Moreover, the blood–brain barrier is not fully developed until after the first year of life, and methyl mercury can cross this incomplete barrier (Rodier 1995).

Three recent, large-scale prospective epidemiologic studies have examined children who experienced methyl mercury exposures *in utero* at concentrations relevant to current U.S. exposure levels. The first of these studies, a cohort in New Zealand, found a 3-point decrement in the Wechsler Intelligence Scale-Revised (WISC-R) full-scale IQ among children born to women with maternal hair mercury concentrations > 6 μg/g (Kjellstrom et al. 1986, 1989). A second study in the Seychelles Islands in the Indian Ocean found only one adverse association with maternal hair mercury concentration among 48 neurodevelopmental end points examined (prolonged time to complete a grooved pegboard test with the nonpreferred hand) (Myers et al. 2003). However, the grooved pegboard test was one of the few neurobehavioral instruments in the Seychelles study not subject to the vagaries of translation that can degrade the validity of culture-bound tests of higher cognitive function when they are applied in developing nations (Landrigan and Goldman 2003). A third prospective study in the Faroe Islands, a component of Denmark inhabited by a Scandinavian population in the North Atlantic, has followed a cohort of children for 14 years and collected data on 17 neurodevelopmental end points, as well as on the impact of methyl mercury on cardiovascular function. The Faroes researchers found significant dose-related, adverse associations between prenatal mercury exposure and performance on a wide range of memory, attention, language, and visual-spatial perception tests (Grandjean et al. 1997). The significance of these associations remained evident when

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blood levels of polychlorinated biphenyls, which are known developmental neurotoxicants (Jacobson and Jacobson 1996), were included in the analysis (Budtz-Jorgensen et al. 2002; Steuerwald et al. 2000). Methyl mercury exposure was also associated with decreased sympathetic- and parasympathetic-mediated modulation of heart rate variability (Grandjean et al. 2004) and with persistent delays in peaks I–III brainstem evoked potentials (Murata et al. 2004).

An assessment of these three prospective studies by the National Academy of Sciences (NAS) (National Research Council 2000) concluded that there is strong evidence for the fetal neurotoxicity of methyl mercury, even at low concentrations of exposure. Moreover, the NAS opined that the most credible of the three prospective epidemiologic studies was the Faroe Islands investigation. In recommending a procedure for setting a reference dose for a methyl mercury standard, the NAS chose to use a linear model to represent the relationship between mercury exposure and neurodevelopmental outcomes, and based this model on the Faroe Islands data. The NAS found that the cord blood methyl mercury concentration was the most sensitive biomarker of exposure *in utero* and correlated best with neurobehavioral outcomes. The NAS was not deterred by the apparently negative findings of the Seychelles Islands study, which it noted was based on a smaller cohort than the Faroe Islands investigation and had only 50% statistical power to detect the effects observed in the Faroes (National Research Council 2000).

Since January 2003, the issue of early life exposure to methyl mercury has become the topic of intense debate after the U.S. Environmental Protection Agency (EPA) announced a proposal to reverse strict controls on emissions of mercury from coal-fired power plants. This proposed "Clear Skies Act" would slow recent progress in controlling mercury emission rates from electric generation facilities and would allow these releases to remain as high as 26 tons/year through 2010 (U.S. EPA 2004a). By contrast, existing protections under the Clean Air Act will limit mercury emissions from coal-fired power plants to 5 tons/year by 2008 (U.S. EPA 2004b). The U.S. EPA's technical analyses in support of "Clear Skies" failed to incorporate or quantify consideration of the health impacts resulting from increased mercury emissions (U.S. EPA 2004c). After legislative momentum for this proposal faded, the U.S. EPA proposed an almost identical Utility Mercury Reductions Rule, which again failed to examine impacts on health. The U.S. EPA issued a final rule on 15 March 2005 (U.S. EPA 2005).

To assess the costs that may result from exposure of the developing brain to methyl mercury, we estimated the economic impact of anthropogenic methyl mercury exposure in the 2000 U.S. birth cohort. We calculated the fraction of this cost that could be attributed to mercury emitted by American electric power generation facilities.

Materials and Methods

Environmentally attributable fraction model. To assess the disease burden and the costs due to methyl mercury exposure, we used an environmentally attributable fraction (EAF) model. The EAF approach was developed by the Institute of Medicine (IOM) to assess the "fractional contribution" of the environment to causation of illness in the United States (IOM 1981), and it has been used to assess the costs of environmental and occupational disease (Fahs et al. 1989; Leigh et al. 1997). It was used recently to estimate the environmentally attributable costs of lead poisoning, asthma, pediatric cancer, and neurodevelopmental disabilities in American children (Landrigan et al. 2002). The EAF is defined by Smith et al. (1999) as "the percentage of a particular disease category that would be eliminated if environmental risk factors were reduced to their lowest feasible concentrations." The EAF is a composite value and is the product of the prevalence of a risk factor multiplied by the relative risk of disease associated with that risk factor. Its calculation is useful in developing strategies for resource allocation and prioritization in public health. The general model developed by the IOM and used in the present analysis is the following:

$$\text{Costs} = \text{disease rate} \times \text{EAF} \times \text{population size} \times \text{cost per case}$$

"Cost per case" refers to discounted lifetime expenditures attributable to a particular disease, including direct costs of health care, costs of rehabilitation, and lost productivity. "Disease rate" and "population size" refer, respectively, to the incidence or prevalence of a disease and the size of the population at risk.

In applying the EAF model, we first reviewed the adverse effects of methyl mercury exposure. We then estimated the costs of those effects and subsequently applied a further fraction to parse out the cost of anthropogenic methyl mercury exposure resulting from emissions of American electrical generation facilities.

Toxic effects of methyl mercury exposure. The NAS found neurodevelopmental effects in the children of women who had consumed fish and seafood during pregnancy to be the most important and best-studied end point for methyl mercury toxicity. Although the NAS identified other potentially significant toxicities resulting from methyl mercury exposure, such as nephrotoxicity and carcinogenicity, those effects were less well characterized (National Research Council 2000). We therefore limited our analysis to the neurodevelopmental impact of methyl mercury toxicity.

There is no evidence to date validating the existence of a threshold blood mercury concentration below which adverse effects on cognition are not seen. The U.S. EPA has, however, set a benchmark dose level (BMDL) for cord blood mercury dose concentration of 58 μg/L. This level that corresponds to the lower limit of the 95% confidence interval for the concentration at which there is a doubling in the Faroes study in the prevalence of test scores (5–10%) in the clinically subnormal range for the Boston Naming Test (Rice et al. 2003). It is important to note that this is not a concentration below which no observed adverse effects were found. The Faroes and New Zealand cohorts both support the conclusion that developmental effects become apparent at levels of approximately 1 ppm mercury in hair, or 5.8 μg/L in cord blood (Grandjean et al. 1997; Kjellstrom et al. 1986, 1989). The Faroes study also found that effects on delayed brainstem auditory responses occurred at much lower exposure concentrations (Murata et al. 2004). In its report, the NAS concluded that the likelihood of subnormal scores on neurodevelopmental tests after *in utero* exposure to methyl mercury increased as cord blood concentrations increased from levels as low as 5 μg/L to the BMDL of 58 μg/L (National Research Council 2000). In light of those findings, we decided in this analysis to apply a no adverse effect level of 5.8 μg/L, the lowest level at which adverse neurodevelopmental effects were demonstrated in the cohort studies.

Recent data suggest that the cord blood mercury concentration may on average be 70% higher than the maternal blood mercury concentration (Stern and Smith 2003), and a recent analysis suggests that a modification of the U.S. EPA reference dose for methyl mercury be made to reflect a cord blood:maternal blood ratio that is > 1 (Stern 2005). If the developmental effects of mercury exposure do, in fact, begin at 5.8 μg/L in cord blood, as suggested by the Faroes (Grandjean et al. 1997) and New Zealand (Kjellstrom et al. 1986, 1989) data and by the NAS report (National Research Council 2000), then effects would occur in children born to women of childbearing age with blood mercury concentrations ≥ 3.41 (ratio, 5.8:1.7) μg/L. National population data from the 1999–2000 National Health and Nutrition Examination Survey (NHANES) found that 15.7% of American women of childbearing age have total blood mercury concentrations ≥ 3.5 μg/L (Mahaffey et al. 2004).

To compute IQ decrements in infants that have resulted from these elevated maternal mercury exposures, we used published data on

percentages of women of childbearing age with mercury concentrations ≥ 3.5, 4.84, 5.8, 7.13, and 15.0 μg/L. We assumed conservatively that all mercury concentrations within each of the segments of the distribution were at the lower bound of the range. We assumed that the probability of giving birth to a child did not correlate with mercury level in a woman of childbearing age. In our base case analysis, we calculated economic costs assuming that children born to women with mercury concentrations 3.5–4.84 μg/L suffer no loss in cognition, and that successive portions of the birth cohort experience loss of cognition associated with cord blood levels of 8.2, 9.9, 12.1, and 25.5 μg/L, respectively.

Recently, the Faroes researchers reviewed their cohort data and found fetal blood mercury concentrations to be only 30% higher than maternal blood concentrations (Budtz-Jorgensen et al. 2004). In light of these findings and to avoid overestimation of the magnitude of impacts, we chose not to include children born to mothers with blood mercury concentrations between 3.5 and 4.84 μg/L in our base case analysis.

To assess the impact on our findings of a range of various possible ratios between maternal and cord blood mercury concentrations, we conducted a sensitivity analysis. In this analysis, we set as a lower bound for our estimate the costs to children with estimated cord blood concentrations ≥ 5.8 μg/L (assuming a cord:maternal blood ratio of 1) and assumed no IQ impact < 4.84 μg/L (assuming a cord:maternal blood ratio of 1.19). This estimate assumed no loss of cognition to children born to women with mercury concentration < 5.8 μg/L and assumed that subsequent portions of the birth cohort experienced cord blood mercury concentrations of 5.8, 7.13, and 15 μg/L, respectively. To estimate economic costs in this scenario, we calculated no costs for children with blood mercury concentrations < 4.84 μg/L. We calculated costs resulting from an incremental increase in blood mercury concentration from 4.84 to 5.8 μg/L in the percentage of the population with blood mercury levels between 5.8 and 7.13 μg/L, and added those costs to the costs resulting from increases from 4.84 to 7.13 μg/L and 4.84 to 15 μg/L in the percentages of the population with concentrations between 7.13 and 15 μg/L and > 15 μg/L, respectively. The result of this calculation is expressed in our analysis as a lower bound for the true economic cost of methyl mercury toxicity to the developing brain.

Impact of methyl mercury exposure on IQ. The Faroes study found that a doubling of mercury concentration was associated with adverse impacts on neurodevelopmental tests ranging from 5.69–15.93% of a standard deviation (Grandjean et al. 1999). Assuming that IQ is normally distributed with a standard deviation of 15 points, a doubling of mercury concentration would be associated with a decrement ranging from 0.85 to 2.4 IQ points. The Faroes researchers used a structural equation analysis to produce estimates of impact of methyl mercury on verbal and motor function at 7 years of age and found an association between a doubling of blood mercury and loss of 9.74% of a standard deviation on motor function and of 10.45% of a standard deviation on verbal function (Budtz-Jorgensen et al. 2002). This analysis suggests that a doubling in mercury concentration produces a decrement of approximately 10% of a standard deviation, or 1.5 IQ points. In the New Zealand study (Kjellstrom et al. 1986, 1989), the average WISC-R full-scale IQ for the study population (n = 237) was 93. In the group with maternal hair mercury > 6 μg/g (~ 4-fold higher than in the study population, n = 61), the average was 90 (Kjellstrom et al. 1989). This finding further supports our use of a loss of 1.5 IQ points for each doubling in our base case analysis. Confounders such as polychlorinated biphenyls did not cause significant confounding of the data in the Faroe Islands study (Budtz-Jorgensen et al. 2002; Steuerwald et al. 2000). As a conservative measure, we nonetheless chose to set as outer bounds for the impact on intelligence of methyl mercury exposure a range of IQ decrements from 0.85 to 2.4 IQ points per doubling, as described by the Faroes researchers (Jorgensen et al. 2004). In applying the EAF methodology, we assume that the relationship between cord blood mercury and IQ is relatively linear over the range of exposures studied (> 5.8 μg/L).

In our sensitivity analysis, we used the same linear dose–response model that was selected by the National Research Council in setting a reference dose for mercury exposure (National Research Council 2000). The Faroes researchers found that, for those children whose mothers had hair mercury concentrations < 10 μg/g, a 1-μg/L increase of cord blood mercury concentration was associated with adverse impacts on neurodevelopmental tests ranging from 3.95 to 8.33% of a standard deviation, or 0.59–1.24 IQ points (average = 0.93 IQ points) (Jorgensen et al. 2004). We also varied the cord:maternal blood mercury ratio from 1 to 1.7 in calculating IQ impact from the linear model as part of our sensitivity analysis. As an upper bound to our cost estimate using the logarithmic model, we calculated the economic cost assuming that children born to women with mercury concentrations 3.5–4.84 μg/L suffer no loss in cognition and that successive portions of the birth cohort experience losses of cognition of 1.21, 1.84, 2.55, and 5.13 IQ points, respectively. The lower-bound estimate assumed that children born to women with mercury concentrations 4.84–5.8 μg/L suffer no loss in cognition and that successive portions of the birth cohort experience losses of cognition of 0.22, 0.48, and 1.39 IQ points.

As an upper bound to our cost estimate using the linear model, we calculated the economic cost assuming that children born to women with mercury concentrations 3.5–4.84 μg/L suffer no loss in cognition and that successive portions of the birth cohort experience losses of cognition of 3.01, 5.04, 7.84, and 24.43 IQ points, respectively. The lower-bound estimate assumed that children born to women with mercury concentrations 4.84–5.8 μg/L suffer no loss in cognition and that successive portions of the birth cohort experience losses of cognition of 0.56, 1.35, and 5.99 IQ points.

Calculation of economic costs of IQ loss. To estimate the costs associated with the cognitive and behavioral consequences of mercury exposure, we relied on an economic forecasting model developed by Schwartz et al. (1985), and we applied this model to NHANES data on prevalence of mercury exposure in women of childbearing age (Schober et al. 2003; Schwartz et al. 1985). In this model, lead concentrations are assumed on the basis of work by Salkever (1995) to produce a dose-related decrement in IQ score. Those decrements in IQ are, in turn, associated with lower wages and diminished lifetime earning power. Salkever used three regression techniques to derive direct and indirect relationships among IQ, schooling, probability of workforce participation, and earnings. He estimated a percentage in lost earnings per IQ point from the percent loss of earnings for each microgram per deciliter increase in blood lead level. Salkever found a 0.473 point decrement in lost lifetime earnings for each microgram per deciliter increase among men and a 0.806 point decrement for each microgram per deciliter increase among women (Salkever 1995). Using Schwartz's (1994) estimate that 0.245 IQ points are lost for each microgram per deciliter increase in blood lead, Salkever (1995) estimated a percentage loss in lifetime earnings per IQ point among men (1.931%) and women (3.225%). We assume that this relationship remains linear across the population range of IQ.

Assuming an annual growth in productivity of 1% and applying a 3% real discount rate, the present value of lifetime expected earnings is $1,032,002 for a boy born in 2000 and $763,468 for a girl born in the same year (Max et al. 2002). The costs of the diminution in this earning power were calculated for the 2000 American birth cohort, using available data on the number of male and female births in 2000 [Centers for Disease Control and Prevention (CDC) 2002a]. We diminished our cost estimate by

0.69%, the infant mortality rate in 2000, to account for those children for whom methyl mercury exposure is unlikely to result in diminished economic productivity (CDC 2002b).

American sources of mercury emission. Mercury emissions result from anthropogenic as well as from natural sources, and we limited our analysis to methyl mercury derived from anthropogenic sources. The UNEP recently estimated that anthropogenic uses account for 70% of the 5,500 tons of mercury released into the earth's atmosphere worldwide (UNEP 2002). Therefore, to limit our analysis to anthropogenic mercury, we applied a 70% factor to convert the cost of lost economic productivity resulting from methyl mercury exposure to the cost attributable to anthropogenic methyl mercury exposure.

We next parsed out the proportion of anthropogenic methyl mercury in fish that arises from American sources and then isolated the subset of that proportion that is emitted by coal-fired electrical generating plants. In 1995, the most recent year for which federal data on the relative deposition of mercury from American and other global sources are available, 158 tons of mercury were emitted to the atmosphere by American anthropogenic sources. Fifty-two (33%) of those 158 tons were deposited in the lower 48 states, whereas the remaining two-thirds were added to the global reservoir (U.S. EPA 2004d). Also in 1995, an additional 35 tons of mercury from the global reservoir were deposited in the United States. Therefore, a total of 87 total tons of mercury were deposited in the United States in that year, of which 60% (52 of 87) were attributable to American anthropogenic sources (U.S. EPA 1996, 1997). This mercury would have been available to bioaccumulate in the marine and aquatic food chains and to enter American freshwater and saltwater fish.

Further complicating our calculations is the fact that not all of the fish sold in America is from American sources. Of the 10.4 billion pounds of edible fish supplied in the United States in 2002, 4.4 billion (42%) are imported from sources outside of the United States (National Marine Fisheries Service 2002). Because U.S. emissions account for 3% of global emissions (UNEP 2002; U.S. EPA 1996), we calculate that the mercury content of imported fish is 2% of American anthropogenic origin: 158 tons of American emissions – 52 tons of American mercury deposited on American soil = 106 tons of American mercury available to contaminate imported fish; 5,500 tons emitted globally – 87 tons deposited on American soil = 5,413 tons of mercury from all sources to contaminate imported fish; 106 tons of mercury available/5,413 tons of mercury from all sources = 0.02, or 2% of mercury in imported fish of American origin. In the remaining 58% of fish consumed in the United States, we assume that 60% of the mercury content comes from American anthropogenic sources (U.S. EPA 1996, 1997). We therefore applied a 36% factor (the weighted average of American sources of mercury content in fish, or $0.6 \times 0.58 + 0.02 \times 0.42$) to specify the economic costs of anthropogenic methyl mercury exposure attributable to American sources.

Modeling supported by the Electric Power Resource Institute (EPRI) estimates that 70% of the mercury deposited in the United States comes from foreign sources (Seigneur et al. 2004). This EPRI analysis also finds that U.S. sources are responsible for > 60% of mercury deposition in the Boston–Washington, D.C. corridor. In one of the model's selected receptor areas—Pines Lake, New Jersey—80% of the deposition originated from U.S. sources, showing that regional deposition can be higher than the 60% number we use in this analysis (Seigneur et al. 2004). In our sensitivity analysis, we varied the factor used to convert the economic cost of anthropogenic methyl mercury exposure to the economic cost attributable to American sources from 18% ($0.3 \times 0.58 + 0.02 \times 0.42$, using EPRI's modeling) to 36% (using federal data on mercury deposition) (Seigneur et al. 2004).

In 1999, the most recent year for which data on American mercury emissions are available, 48 (41%) of the 117 tons of mercury emissions from anthropogenic sources in the United States were emitted by electric power generation facilities (U.S. EPA 2003a). To calculate the economic cost of methyl mercury exposure attributable to these facilities, we applied an additional fraction of 41% in our analysis.

Results

Base-case analysis. Each year in the United States, between 316,588 (7.8% of the annual birth cohort) and 637,233 babies are born with cord blood mercury levels > 5.8 μg/L. The lower-bound estimate of 316,588 babies is based on the very conservative assumption that maternal and cord blood mercury concentrations are equal. But if the cord blood mercury concentration is on average 70% higher than the maternal blood mercury concentration, as suggested by recent research (Stern and Smith 2003), 637,233 babies, or 15.7% of the birth cohort, experience cord blood mercury levels > 5.8 μg/L. Fetal blood mercury levels > 5.8 μg/L are associated with small but significant loss of IQ. This decrement in IQ appears to be permanent and irreversible, and it adversely affects a significant portion of the annual birth cohort's economic productivity over a lifetime.

Using our base-case assumptions (impact for women with total mercury > 4.84 μg/L, cord:maternal mercury ratio = 1.7, IQ impact = 1.5 points per doubling), we calculated costs for the 405,881 children who suffer IQ decrements resulting from fetal methyl mercury exposure. Under these assumptions, 89,293 children suffered a 0.76 decrement in IQ and another 113,647 experienced a 1.15 IQ point decrement. The 5% most highly exposed children in the 2000 birth cohort suffered subclinical losses in IQ in our model ranging from 1.60 to 3.21 points. Although this diminution in intelligence is small in comparison with the loss of cognition that can result from other genetic and environmental processes, the loss resulting from methyl mercury exposure produces a significant reduction in economic productivity over a lifetime. We estimate the aggregate cost of the loss in IQ that results from exposure of American children to methyl mercury of anthropogenic origin to be $8.7 billion (all costs in 2000 US$) annually (Table 1).

Sensitivity analysis. We estimate that the cost of anthropogenic methyl mercury exposure ranges from $2.2 billion (impact only for the 316,588 children born to women with total mercury > 5.8 μg/L, IQ impact = 0.85 points per doubling) to $13.9 billion (impact for the 405,881 women with total mercury > 4.84 μg/L, IQ impact = 2.4 points per doubling). Using the linear dose–response model that was selected by the National Research Council in recommending a reference dose for mercury exposure (a model that predicts an average loss of 0.93 IQ points per 1-μg/L increase in mercury concentration) (Jorgensen et al. 2004; National Research Council 2000), we find that the environmentally attributable cost of methyl mercury exposure is $32.9 billion, assuming a cord:maternal blood mercury ratio of 1.7. Employing a linear model and assuming that the true loss in IQ resulting from a 1-μg/L increase in blood mercury ranges from 0.59 to 1.24 points, we find that the outer bounds of our estimate range from $7.0 billion (impact only for women with total mercury > 5.8 μg/L, IQ impact = 0.59 points per μg/L increase, cord:maternal mercury ratio = 1) to $43.8 billion (impact for women with total mercury > 4.84 μg/L, IQ impact = 1.24 points for each microgram per deciliter increase, cord:maternal mercury ratio = 1.7) (Table 2).

Sources of costs. After applying the 36% fraction to restrict our analysis to American anthropogenic sources, we estimate that the attributable cost of methyl mercury exposure to the developing fetus from American anthropogenic sources is $3.1 billion annually, using the logarithmic model developed by the Faroes researchers (Grandjean et al. 1999; Jorgensen et al. 2004) and assuming a 1.5-point IQ impact for each doubling of methyl mercury exposure (Budtz-Jorgensen

et al. 2002). Our sensitivity analysis, in which we also varied the attributable fraction for American sources from 18% (industry data sources) to 36% (federal data sources) (Seigneur et al. 2004; U.S. EPA 1996, 1997), suggests that the true cost of methyl mercury exposure from American emissions ranges from $0.4 to $15.8 billion annually.

To focus specifically on the costs of fetal exposure to mercury released by American coal-fired power plants, we examined the impact of the 41% of U.S. anthropogenic emissions of mercury attributable to these facilities. We estimate that the attributable cost of methyl mercury exposure from American electric generation facilities to the developing fetus is $1.3 billion. Applying our sensitivity analysis in this model, we find that the true cost of methyl mercury exposure from electric generation facilities to the American birth cohort ranges from $0.1 to $6.5 billion/year (Figure 1). Again, the major source of these costs is loss of earnings over a lifetime.

Discussion

The major findings in this analysis are *a*) that exposure to methyl mercury emitted to the atmosphere by American electric generation facilities causes lifelong loss of intelligence in hundreds of thousands of American babies born each year and *b*) that this loss of intelligence exacts a significant economic cost to American society, a cost that amounts to at least hundreds of millions of dollars each year. Moreover, these costs will recur each year with each new birth cohort as long as mercury emissions are not controlled. By contrast, the cost of installing stack filters to control atmospheric mercury emissions is a one-time expense. The high costs of *in utero* exposure to methyl mercury are due principally to the lifelong consequences of irreversible injury to the developing brain. Similar lifelong neurobehavioral consequences have been observed after exposure of the developing brain to other environmental toxicants, including lead (Baghurst et al. 1987; Bellinger 2004; Dietrich et al. 1987; Opler et al. 2004; Wasserman et al. 2000), polychlorinated biphenyls (Jacobson and Jacobson 1996), and ethanol (Lupton et al. 2004).

Because the literature has presented a range of possible consequences for methyl mercury toxicity, we have provided a range of possible public health and economic consequences. This range is meant to inform the choices that environmental and public health officials make in protecting vulnerable populations from methyl mercury exposure. Our range for the true economic costs of methyl mercury toxicity to the developing brain omits the cost of exposures to the 231,352 children born to women in 2000 with blood mercury concentrations between 3.5 and 4.84 μg/L. If the true cord blood ratio is 1.7 times the maternal blood concentration, as described in the most recent and extensive meta-analysis on the matter (Stern and Smith 2003), these children are also born with cord blood mercury concentrations above the 5.8 μg/L concentration at which adverse neurodevelopmental impact has been found. We chose not to include them in our analysis because other studies have found lower ratios and because we restricted ourselves in this analysis to the use of available, published prevalence data of maternal blood mercury concentrations. In our sensitivity analysis, we also selected low cord:maternal blood ratios so as to describe most accurately the range of values for the true cost of methyl mercury exposure to the developing fetus.

Our analysis also omits the cost of the cardiovascular impacts of mercury exposure (Grandjean et al. 2004) or the costs of mercury exposure to children in the first 2 years of postnatal life, when myelination is still continuing and the blood–brain barrier remains vulnerable to penetration by methyl mercury (Rodier 1995). We chose not to include these aspects of methyl mercury toxicity in our range of estimates at this time because there do not exist sufficient quantitative data to permit construction of a reliable model.

A limitation on our analysis is that it did not consider other societal costs beyond decreased lifetime earnings that may result from exposure of the developing brain to methyl mercury. For example, if the value of a child's social productivity is approximately $4–9 million, as suggested by studies of willingness-to-pay (WTP) estimates of a life (Viscusi and Aldy 2004), then by the WTP methodology the true cost of methyl mercury toxicity may be much higher than our estimate. We also chose not to include other noncognitive impacts. Lead, for example, has been associated with criminality and antisocial behavior (Dietrich et al. 2001; Needleman et al. 1996, 2002; Nevin 2000; Stretesky and Lynch 2001). However, because these behaviors have not been described as yet for methyl mercury, we chose not to include such costs in our estimate.

Some will argue that our range of costs fails to incorporate the role of confounding factors in quantifying the economic consequences of methyl mercury exposure. It is true that efforts

Table 1. Cost of anthropogenic mercury (Hg) exposure using a logarithmic model.

Variable	Segment of population (percentile)			
	90–92.1 Hg	92.2–94.9 Hg	95–99.3 Hg	≥ 99.4 Hg
Range of maternal total Hg concentration	4.84–5.8 μg/L	5.8–7.13 μg/L	7.13–15.0 μg/L	> 15.0 μg/L
Assumed maternal total Hg concentration	4.84	5.8	7.13	15
No effect concentration (maternal total Hg)	3.41	3.41	3.41	3.41
IQ points lost at assumed concentration	0.76	1.15	1.60	3.21
Loss of 1 IQ points = decrease in lifetime earnings				
For boys, lifetime earnings (1.931% decrease)			$1,032,002	
For girls, lifetime earnings (3.225% decrease)			$763,468	
No. of boys in birth cohort affected	45,693	58,155	91,387	12,462
No. of girls in birth cohort affected	43,601	55,492	87,201	11,891
Lost income	$1.1 billion	$2.0 billion	$4.4 billion	$1.2 billion
Total cost = $8.7 billion in each year's birth cohort				

Assumptions: EAF = 70%, main consequence = loss of IQ over lifetime.

Table 2. Sensitivity analysis: cost of anthropogenic methyl mercury exposure.

Variable	Base-case cost estimate (range)[a]
Children born to women with Hg > 4.84 μg/L, effect > 3.5 μg/L	
Logarithmic model	$8.7 billion ($4.9–13.9 billion)
Linear model, cord:maternal Hg ratio = 1.7	$32.9 billion ($20.9–43.8 billion)
Linear model, cord:maternal Hg ratio = 1	$19.3 billion ($12.3–25.8 billion)
Children born to women with > 5.8 μg/L, effect > 4.84 μg/L	
Logarithmic model	$3.9 billion ($2.2–6.3 billion)
Linear model, cord:maternal Hg ratio = 1.7	$18.7 billion ($11.9–24.9 billion)
Linear model, cord:maternal Hg ratio = 1	$11.0 billion ($7.0–14.6 billion)
Range of estimates	
Logarithmic model	$2.2–13.9 billion
Linear model	$7.0–43.8 billion

Assumptions: EAF = 70%, main consequence = loss of IQ over lifetime.
[a]Based on range of possible IQ decrement:increase cord blood mercury.

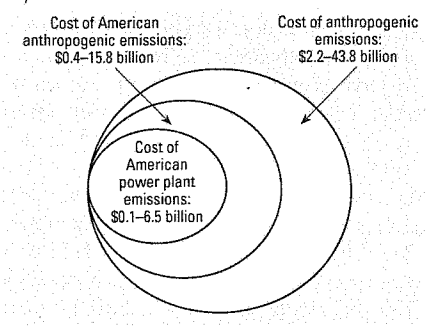

Figure 1. Portions of cost of methyl mercury exposure attributed to sources. Assumptions: 18–36% attributable to American sources; 41% of American emissions attributable to American power plants.

to delineate the potential synergistic role of methyl mercury and other chemicals in mediating neurocognitive and other effects are bedeviled by lack of knowledge about possible interactions and synergies among chemicals or between chemicals and other environmental hazards, even though the environment of a child includes mixtures of chemical and biologic toxicants. Only a study of the magnitude of the National Children's Study will facilitate simultaneous examination of the effects of multiple chemical exposures, of interactions among them, and of interactions among biologic, chemical, behavioral, and social factors (Trasande and Landrigan 2004). However, we note that loss of cognition resulting from methyl mercury exposure in the Faroe Islands study remained evident when blood levels of polychlorinated biphenyls, which are known fetal neurotoxicants (Jacobson and Jacobson 1996), were included in the analysis (Budtz-Jorgensen et al. 2002; Steuerwald et al. 2000).

We note the U.S. EPA's recent success in minimizing mercury emissions from medical waste (U.S. EPA 2004e) and municipal incinerators (U.S. EPA 2004f, 2004g), actions that resulted in a decrease in total mercury emissions by at least 80 tons per year from 1990 to 1999 (U.S. EPA 2003b). Although data are not available on blood mercury concentrations over the past decade that followed from those actions, the impact of these reductions is likely to have been substantial.

Some commentators have used data from the Seychelles study to argue that methyl mercury is not toxic to the fetus at low concentrations and to suggest that fear of mercury exposure is needlessly preventing women from ingesting fish and thus denying them access to beneficial long-chain polyunsaturated fatty acids (LCPUFAs), especially docosahexaenoic acid (DHA). We do not dispute that DHA and other LCPUFAs are important for optimal development of the fetal visual and nervous systems (Innis 1991). The human fetus has a limited ability to synthesize DHA's precursor, α-linolenic acid, and therefore it must be largely supplied from maternal sources (Carnielli et al. 1996; Larque et al. 2002; Szitanyi et al. 1999). We also note a report that associated an average monthly decline in fish consumption of 1.4 servings among Massachusetts women with a U.S. Food and Drug Administration advisory on the health risks of mercury (Oken et al. 2003). Nonetheless, the American Heart Association, a strong advocate for the cardioprotective effects of LCPUFAs, recommends that children and pregnant and lactating women avoid potentially contaminated fish (Kris-Etherton et al. 2002). Fish advisories should not recommend that consumers abstain from fish, but they should assist in choosing the best kinds of fish to eat. Lists of fish that are safe and unsafe from the perspective of mercury exposure have been published and made widely available to consumers (U.S. EPA 2004h).

Early reports of disease and dysfunction of environmental origin in children have on repeated occasions failed to produce proactive response to protect children. The long history of lead use in the United States provides a chilling reminder of the consequences of failure to act on early evidence of harm. It is important that we not repeat this sequence with mercury. Within the last century, as a result of increased industrial activity, mercury emissions worldwide have increased 2- to 5-fold, and anthropogenic emissions now surpass emissions from natural sources (Nriagu 1989).

The data from this analysis reinforce the results of recent epidemiologic studies and indicate an urgent need on economic grounds for regulatory intervention at the federal level to minimize mercury emissions. Our analysis captures the cost of methyl mercury exposure for only 1 year's birth cohort, but the cost of mercury exposure will continue to accrue in each succeeding year if power plants fail to install flue gas filters (U.S. Department of Energy 2004) or to implement other technologies to reduce mercury emissions. The cost savings from reducing mercury exposure now will provide savings in improved productivity and enhanced national security for generations to come.

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Appendix H:
Additional Analyses of Mercury Emissions Needed Before EPA Finalizes Rules for Coal-Fired Electric Utilities

OFFICE OF INSPECTOR GENERAL

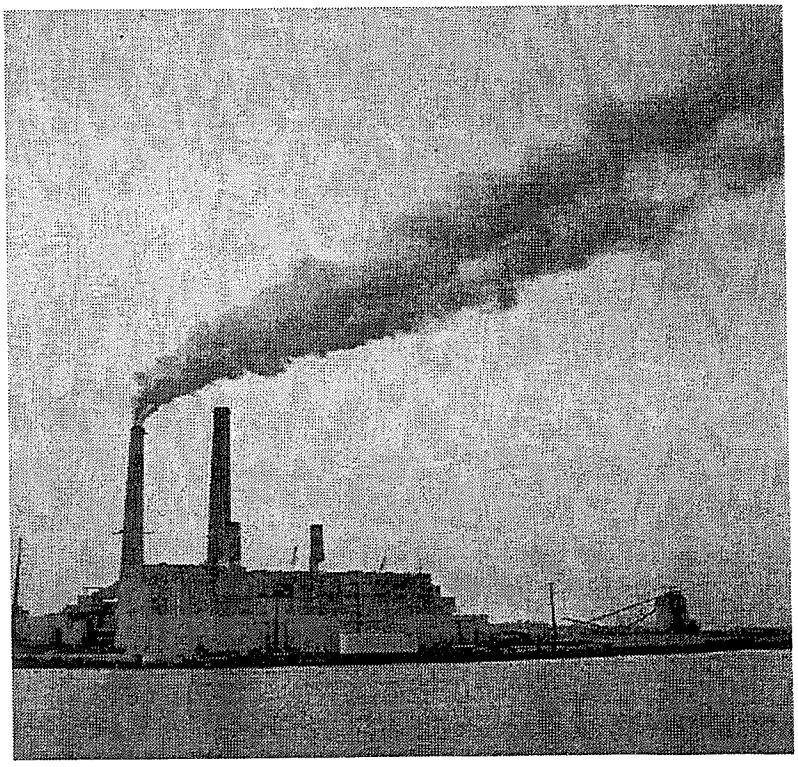
Catalyst for Improving the Environment

Evaluation Report

Additional Analyses of Mercury Emissions Needed Before EPA Finalizes Rules for Coal-Fired Electric Utilities

Report No. 2005-P-00003

February 3, 2005



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Abbreviations

CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CHPAC	Children's Health Protection Advisory Committee
EPA	Environmental Protection Agency
FACA	Federal Advisory Committee Act
OIG	Office of Inspector General
ICR	Information Collection Request
IGCC	Integrated Gasification Combined Cycle
IPM	Integrated Planning Model
OMB	Office of Management and Budget
MACT	Maximum Achievable Control Technology
NTEC	National Tribal Environmental Council
NO_X	Nitrogen Oxide
OCHP	Office of Children's Health Protection
SO_2	Sulfur Dioxide

Cover photo: Virginia Electric Power Company's coal-fired plant at Mt. Storm, West Virginia.
Source: http://www.oag.state.ny.us/press/2000/nov/nov16a_00_pictures.html

U.S. Environmental Protection Agency
Office of Inspector General

2005-P-00003
February 3, 2005

At a Glance

Catalyst for Improving the Environment

Why We Did This Review

Members of the Senate Environment and Public Works Committee requested that we review EPA's development of its proposed rule for controlling mercury emissions from coal-fired electric utilities.

Background

Coal-fired electric utilities represent the largest source of airborne mercury emissions in the United States. Once airborne, mercury can be deposited into water, where it bio-accumulates in fish and animals at the top of the food chain. Human consumption of fish is the primary method of exposure to mercury, which has been shown to cause neurological and fetal developmental problems.

On January 30, 2004, EPA proposed rules for regulating mercury emissions from coal-fired steam generating electric utility units. EPA proposed two options for controlling mercury emissions, one a control technology standard with emission limits and the other a performance based cap-and-trade approach.

For further information, contact our Office of Congressional and Public Liaison at (202) 566-2391.

To view the full report, click on the following link: www.epa.gov/oig/reports/2005/20050203-2005-P-00003.pdf

Additional Analyses of Mercury Emissions Needed Before EPA Finalizes Rules for Coal-Fired Electric Utilities

What We Found

Evidence indicates that EPA senior management instructed EPA staff to develop a Maximum Achievable Control Technology (MACT) standard for mercury that would result in national emissions of 34 tons annually, instead of basing the standard on an unbiased determination of what the top performing units were achieving in practice. The 34-tons-per-year target was based on the amount of mercury reductions expected to be achieved from implementation of nitrogen oxide (NOx) and sulfur dioxide (SO_2) controls under a separately proposed, but related, air rule. According to EPA officials, 34 tons represents the most realistic and achievable standard for utilities. However, because the results of the MACT standard were prescribed and prior estimates were lower than what was proposed, the standard likely understates the average amount of mercury emissions reductions achieved by the top performing 12 percent of utilities, the minimum level for a MACT standard required by the Clean Air Act. Further, this MACT standard, as proposed, does not provide a reasonable basis for determining whether the MACT or cap-and-trade approach provides the better cost benefit.

The Agency's cap-and-trade proposal can be strengthened to better ensure that anticipated emission reductions would be achieved. For example, utilities would not need to install mercury-specific controls to achieve the interim cap, but could meet the cap by implementing NOx and SO_2 controls associated with another proposed trading program. Also, the proposal does not adequately address the potential for hot spots. Further, provisions for units emitting small amounts of mercury could be improved.

We also found that EPA's rule development process did not comply with certain Agency and Executive Order requirements, including not fully analyzing the cost-benefit of regulatory alternatives and not fully assessing the rule's impact on children's health.

What We Recommend

We recommend that EPA re-analyze mercury emissions data collected for the top performing 12 percent of units to develop a MACT floor. The Agency should also conduct a revised cost-benefit analysis for the updated MACT that takes into account the impact of mercury co-benefits achieved through the proposed Clean Air Interstate Rule. The results of the cost-benefit review should be compared to the cost-benefit of the proposed cap-and-trade option to determine the most cost beneficial option for controlling mercury emissions. We also recommend that EPA strengthen its cap-and-trade proposal by more fully addressing the potential for hot spots; revising the safety valve proposal so that it is used only as intended during periods of unanticipated market volatility; and revising the proposed exemption for small emitters. Further, we recommend that the Agency conduct more in-depth analyses of the regulatory alternatives and children's health impacts as required by Executive Orders. The Agency's response to the draft report did not specifically address our recommendations, but raised concerns about certain aspects of the report.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

THE INSPECTOR GENERAL

February 3, 2005

MEMORANDUM

SUBJECT: Evaluation Report: Additional Analyses of Mercury Emissions Needed Before EPA Finalizes Rules for Coal-Fired Electric Utilities
Report No. 2005-P-00003

TO: Jeffrey R. Holmstead
Assistant Administrator for Air and Radiation

This memorandum transmits the results of an Office of Inspector General (OIG) evaluation regarding the Environmental Protection Agency's (EPA) development of the proposed rule for regulating mercury emissions from coal-fired steam generating electric utility units. This report contains findings that should help EPA in its efforts to develop the final rule. Also, the report contains corrective actions the Office of Inspector General (OIG) recommends. This report represents the opinion of the OIG and the findings contained in this report do not necessarily represent the final EPA position. Final determinations on matters in this report will be made by EPA managers in accordance with established procedures.

Action Required

In accordance with EPA Directive 2750, as the action official, you are required to provide this Office with a written response within 90 days of the final report date. The response should address all recommendations. For the corrective actions planned but not completed by the response date, please describe the actions that are ongoing and provide a timetable for completion. Where you disagree with a recommendation, please provide alternative actions for addressing the findings reported.

We appreciate the efforts of EPA officials and staff in working with us to develop this report. If you or your staff have any questions regarding this report, please contact me at (202) 566-0847 or Kwai Chan, Assistant Inspector General for Program Evaluation, at (202) 566-0827.

Nikki L. Tinsley

Attachment

cc: Steve Johnson, Acting Administrator
William Farland, Acting Deputy Assistant Administrator for Science, ORD
Ann Klee, General Counsel
Pete Cosier, Audit Followup Coordinator, OAR
Kwai Chan, Assistant Inspector General for Program Evaluation, OIG
Mark Bialek, Counsel, OIG

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Chapter 1
Introduction

Purpose

The Office of Inspector General (OIG) initiated this review based on a request from members of the Senate Environment and Public Works Committee. In their written request, the Senators expressed concerns with the process used to develop the Environmental Protection Agency's (EPA's) January 2004 proposed rule for regulating mercury emissions from coal-fired steam generating electric utility units. The proposed rule included two different options for regulating mercury emissions. One approach was a Maximum Achievable Control Technology (MACT) standard that would establish emission limits applicable to all coal-fired utility units. The other approach was a mercury cap-and-trade approach that would establish a national cap on mercury emissions and allow individual utilities to trade emissions allowances in a market-based system. The objectives of our evaluation were to determine:

- Do the data and analyses in the docket demonstrate that the proposed MACT option reflects the maximum achievable reductions from coal-fired steam generating electric utility units?
- Is the mercury cap-and-trade option, as proposed, sufficient to ensure public health protection?
- What process did EPA follow in developing the proposed rule, and was this process consistent with applicable statutes, regulations, policy, guidance, and past Agency practice?

Background

Mercury is released globally into the environment through natural processes, such as volcanoes, and also from human activity. Man-made releases of mercury are primarily due to the burning of mercury-containing fuels and wastes, and through industrial manufacturing processes. Man-made mercury emissions from the United States are estimated to account for roughly 3 percent of total global mercury emissions. Mercury from lead smelters, municipal waste combustors, hospital waste incinerators, manufacturing operations, and other sources are largely already regulated by EPA. In the United States, the largest source of airborne mercury emissions is the coal-burning electric utilities industry, representing an estimated 40 percent of total U.S. man-made airborne mercury

emissions. EPA has estimated that one-third of all U.S. emissions of mercury are deposited within the contiguous United States, while the remaining two-thirds enter the global cycle. The January 2004 proposal is the first attempt to regulate mercury emissions from these utilities at the Federal level.

Airborne concentrations of mercury are generally considered to be small and not a serious health concern while still in the air. However, once mercury enters fresh-water and salt-water bodies, either directly or through air deposition, it can bioaccumulate in fish and other animal tissues in its more toxic form, methylmercury. As mercury bioaccumulates in the food chain, its concentration becomes increasingly higher in animals at the top of the food chain (such as larger predatory fish) that consume smaller contaminated organisms. Because of the bioaccumulation of methylmercury, the primary route of human exposure to mercury is through the consumption of fish, both salt water and fresh water. Excessive human exposure to mercury has been associated with severe detrimental neurological and developmental health effects. Depending on the dose, human health effects from exposure to mercury can include subtle losses of sensory and cognitive ability, tremors, inability to walk, and death. The developing fetus may be particularly sensitive to the detrimental effects of methylmercury; thus, exposure to mercury by women of child-bearing age is of particular concern.

From a global perspective, mercury accumulation in salt-water fish is a public health concern. EPA and the Food and Drug Administration have cautioned that young children, as well as women who might become pregnant, are pregnant, or are nursing should limit their consumption of certain salt-water predatory fish. Mercury bioaccumulation in U.S. water bodies is also a public health concern, and 45 States issued fish advisories for mercury in 2003. Many of these fish advisories caution that women and young children should limit their consumption of certain types of fish.

EPA Reference Dose for Methylmercury

Based on studies showing adverse health effects from exposure to methylmercury, EPA set a reference dose for methylmercury that was designed to protect the most sensitive subgroup (i.e., developing fetuses). An EPA reference dose reflects the estimate of daily exposure to the human population, including sensitive subgroups, that is not likely to cause harmful effects during a lifetime. The current EPA reference dose for methylmercury – which was included in EPA's 1997 Mercury Study Report to Congress – is 0.1 micrograms per kilogram of body weight per day.

Subsequent to EPA's 1997 Mercury Study Report to Congress, Congress directed[1] EPA to request the National Academy of Sciences to perform an independent study on the toxicological effects of methylmercury and to prepare recommendations on the establishment of a scientifically appropriate exposure reference dose. The National Academy of Sciences completed its review in 2000, and concluded that the EPA reference dose of 0.1 micrograms per kilogram was a scientifically justifiable level for the protection of health.

The most recent results from Centers for Disease Control and Prevention's ongoing National Health and Nutrition Examination Survey show that mercury blood levels of most children and women of childbearing age were below levels of concern corresponding to the EPA reference dose. However, 5.66 percent of childbearing-aged woman had blood mercury levels at or above the reference dose. The survey also questions participants about their fish consumption. For the 1999-2000 survey period, tuna and shrimp were the two most frequently cited types of fish/shellfish consumed. These results, and other studies, suggest that seafood (as opposed to fresh-water fish) is the predominant source of mercury exposure in the United States. However, some subpopulations in the United States consume more fish, including fresh-water fish, than the general population. These groups may be at increased risk from mercury exposure. For example, studies have shown elevated blood levels of mercury in some Native American tribes that consumed fresh-water fish.

Statutory Requirements for Controlling Mercury Emissions from Utility Plants

The Clean Air Act (CAA) requires EPA to regulate emissions of 188 air toxics (also known as hazardous air pollutants), including mercury. EPA was to identify and establish emission standards for major source categories emitting these pollutants. Specifically, section 112(d) of the CAA requires EPA to establish emission limits for major source categories emitting air toxics, commonly referred to as MACT standards. The MACT standard is to require the maximum degree of reductions achievable for the source category, taking into consideration cost and any non-air quality health and environmental impacts.

A key requirement of section 112(d) is that emission standards for existing sources in a category or subcategory shall not be less stringent than the average emission limitation achieved by the best performing 12 percent of the existing sources for which the Administrator has data. The emission limitation achieved by the best performing 12 percent of sources is referred to as the "MACT floor."

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[1] H.R. Rep. No. 769, 105th Cong., 2d Sess. at 281-282 (1998). This is the Conference Report to accompany H.R. 4194, October 5, 1998.

The CAA also established specific requirements with respect to air toxics emissions from utilities. Section 112(n)(1)(A) requires EPA to perform a study of the hazards to public health that are reasonably anticipated to occur as a result of air toxics emissions from electric utility steam generating units. This study was to develop and describe alternative control strategies for emissions that may warrant regulation under section 112. Further, with respect to regulating emissions from utility plants, section 112(n)(1)(A) states:

> *The Administrator shall regulate electric utility steam generating units under this section, if the Administrator finds such regulation is appropriate and necessary after considering the results of the study required by this subparagraph.*

EPA published its Final Report[2] with respect to utilities in February 1998, but deferred making a determination as to whether regulation of these units was appropriate and necessary. However, the Final Report concluded that:

- Mercury from coal-fired utilities was the air pollutant of greatest potential concern to public health from utilities;
- Coal-fired utilities are estimated to emit about one-third (51 tons based on 1994 emissions) of U.S. anthropogenic (man-made) mercury emissions per year;
- Ingestion of contaminated fish is the most important route of exposure to mercury; and
- Modeling in conjunction with the available scientific data provides evidence for a plausible link between emissions of mercury from utilities and the methylmercury found in soil, water, air, and fish.

In its Final Report, EPA listed a number of research needs related to mercury emissions. These included obtaining additional data on mercury emissions, such as the amount emitted from various types of units; the proportion of divalent versus elemental mercury;[3] and how factors such as the control device, fuel type, and plant configuration affect emissions and speciation.

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[2] Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units - - Final Report to Congress, EPA-453/R-98-004a, February 1998.

[3] Airborne divalent mercury is adsorbed onto particles or bound to other compounds and is deposited sooner and mainly in the vicinity of the emissions sources (local to regional distances), while elemental mercury (vapor) remains airborne longer and is transported on a hemispherical/global scale.

Information Collection Request

Based on the research needs outlined in the Final Report, the then-EPA Administrator concluded that obtaining additional information from owner/operators of coal-fired electric utility steam generating units was needed to determine whether regulation of electric utility steam generating units was appropriate and necessary. Accordingly, EPA used its authority under CAA section 114 to collect data from all domestic coal-fired electric utility steam generating units. The resulting information collection request (ICR) consisted of three phases of data collection:

- **Phase I** collected general information on every coal-fired electric generating utility unit and was completed in January 1999.

- **Phase II** consisted of obtaining information on the amount of coal received on a per shipment basis for the 1999 calendar year for every facility. In addition, the mercury and chlorine content of the coal was reported for every sixth shipment.

- **Phase III** consisted of emissions testing at 80 units,[4] which were selected to represent a cross-section of boiler and control device types. For each of the 80 units selected, testing for mercury was conducted at the inlet and outlet of the last pollution control device on the unit. Each unit was to conduct three separate test runs and to also sample and analyze the coal used during each of the three separate runs.

December 2000 Findings and Determination

In a December 20, 2000, Federal Register Notice, EPA published its finding that regulation of mercury emissions from coal-fired utility plants was appropriate and necessary. The notice described four primary sources of information for the finding:

- EPA's February 1998 "Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units -- Final Report to Congress."
- An ICR to all coal-fired electric utility steam generating units requesting coal data for 1999 and a request to certain units for stack test results to evaluate air toxics emissions.
- An evaluation of the mercury control performance of various emission control technologies currently in use to control other pollutants or that could be applied to such units to control mercury emissions.

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[4] Emission tests were actually conducted at 79 different units with 2 tests conducted at 1 unit for a total of 80 tests.

- An evaluation of available health data related to mercury conducted by the National Academy of Sciences.

The Notice concluded that, ". . . during the regulatory development process, effective controls for mercury and other HAPs (hazardous air pollutants) can be shown to be feasible." The Notice recognized the considerable interest in using economic incentive programs, such as emission trading, to achieve emission reductions. However, in its December 2000 notice, EPA cited concerns about the potential local impact of emissions trading and noted that any trading program must be constructed in a way that assured communities nearest a source were adequately protected. The Notice stated:

> *Thus, in developing a standard for utilities, the EPA should consider the legal potential for, and the economic effects of, incorporating a trading regime under section 112 in a manner that protects the local populations.*

After issuance of these findings and its determination that regulation of utilities was appropriate and necessary, EPA began to develop a MACT standard for mercury emissions from coal-fired electric utility units. Additionally, a workgroup was established in August 2001 under the Clean Air Act Advisory Committee to provide EPA with input regarding Federal MACT regulations for coal-fired electric utility steam generating units. Appendix A provides a timeline of events associated with the development of the MACT rule.

Clear Skies Proposal

Concurrent with EPA's initial efforts to develop a MACT for utility units, legislation was proposed in Congress[5] to establish a multi-pollutant approach for addressing mercury, sulfur dioxide (SO_2), and nitrogen oxide (NOx) emissions from utilities. This legislation, referred to as Clear Skies, proposed a cap-and-trade approach to controlling emissions of these three pollutants. With respect to mercury, the initial Clear Skies legislation called for an interim cap on total U.S. mercury emissions of 26 tons per year by 2010. Based on modeling done in support of the Clear Skies Proposal, EPA estimated that some facilities would install mercury-specific technology by 2010 in order to meet the 26-ton cap. Clear Skies proposed a final cap of 15 tons on mercury emissions by 2018, and EPA analysis projected that additional sources would choose to install mercury-specific controls to meet the cap.

When Clear Skies legislation stalled in Congress, EPA decided to propose a cap-and-trade approach for controlling mercury emissions as an alternative to a

[5] Clear Skies was proposed in both the U.S. House of Representatives and Senate in July 2002, and reintroduced as the Clear Skies Act of 2003 on February 27, 2003.

MACT standard. EPA proposed these regulatory alternatives in the January 30, 2004, Federal Register Notice. In addition to the proposed mercury rule alternatives, EPA on January 30, 2004, also proposed new air rules for reducing SO_2 and NOx emissions. This proposed rule, now known as the Clean Air Interstate Rule (CAIR), would establish a cap-and-trade program for 29 States in the Eastern United States and the District of Columbia whose SO_2 and NOx emissions significantly contribute to fine particle and ozone pollution problems in other downwind States. Together, the CAIR and mercury proposals would create a multi-pollutant approach to controlling emissions from utilities similar to what was originally proposed in the Clear Skies legislation.

Proposed Mercury Rule

As a result of a prior court settlement[6], EPA had agreed to issue proposed power plant mercury emission standards by December 15, 2003. In the January 30, 2004, Federal Register Notice, EPA proposed its rule for regulating mercury emissions from coal-fired steam generating electric utility units. This proposal includes two different approaches for controlling mercury emissions from utilities: a MACT standard or a mercury cap-and-trade program.

EPA's Proposed MACT Standard Approach: EPA proposed separate emission limits to be achieved by 2008 for five subcategories: three subcategories for different coal types (bituminous, sub-bituminous, and lignite); one for coal refuse or waste; and one for a specific type of combustion process known as Integrated Gasification Combined Cycle (IGCC).[7] Table 1-1 shows the specific per unit emissions limits for existing units in the proposed rule.

Table 1-1: Proposed MACT Emission Limits

Subcategory	Emission limit (lbs/TBtu)*
Bituminous	2.0
Sub-bituminous	5.8
Lignite	9.2
Coal-Refuse	0.38
IGCC	19.0

* = pounds per Trillion British thermal units.

These emission limits were based on what EPA determined to be the MACT floor. EPA proposed that the MACT standard be based on the MACT floor as

[6] Under a settlement agreement reached in 1998 with the Natural Resources Defense Council, EPA agreed to issue a proposed rule for regulating mercury from power plants by December 15, 2003, and a final rule by December 2004. (*Natural Resources Defense Council v. EPA*,D.C. Cir., No. 92-1415, 4/15/98). Natural Resources Defense Council later agreed to extend the deadline for the final rule to March 15, 2005.

[7] The IGCC process converts coal into gas and uses the coal gas as fuel for generating electricity.

opposed to a beyond-the-floor[8] level because it concluded that technologies for reducing mercury emissions were not commercially available and, thus, beyond-the-floor emission standards were not achievable. EPA estimated that total national mercury emissions would be reduced from 48 to 34 tons per year if the proposed MACT rule was implemented.

EPA's Proposed Cap-and-Trade Approach. In lieu of adopting a MACT standard to regulate mercury emissions from utilities, EPA presented an alternative proposal that would regulate mercury emissions from utility units under a national cap-and-trade program implemented under section 111 of the CAA.[9] The cap-and-trade proposal included an unspecified interim cap on mercury emissions in 2010 and a final cap of 15 tons by 2018. Though EPA did not specify an interim cap level, the Agency proposed that it be based on the maximum amount of mercury reductions that could be achieved through implementing the controls necessary to reduce SO_2 and NOx emissions, i.e., the mercury co-benefit of these controls through implementation of CAIR. The preamble to the rule states that EPA modeling indicated an expected co-benefit level, which is the result of implementing the CAIR rule, resulting in mercury emissions of 34 tons per year. EPA also took comment on administering the cap-and-trade approach under CAA section 112 instead of section 111.[10] The primary difference between these two approaches is that a section 112 cap-and-trade program would be administered centrally by EPA while the section 111 program would be administered individually by States.

Scope and Methodology

We conducted our field work from May 2004 through December 2004, and did so in accordance with *Government Auditing Standards*, issued by the Comptroller General of the United States. We performed field work in EPA's Office of Air and Radiation locations in Washington, DC, and Research Triangle Park, North Carolina. We interviewed staff from EPA offices and outside organizations to gain an understanding of the rule as developed, other options considered, and the rule development process. We interviewed officials from EPA's Office of Air and Radiation; Office of Research and Development; Office of Enforcement and Compliance Assurance; and Office of Policy, Economics, and Innovation. We also contacted environmental and utility industry representatives, and State, local, and tribal organizations interested in the development of this proposed rule, to

[8] A MACT standard more stringent than the floor is referred to as "beyond-the-floor."

[9] Concurrent with this approach, EPA proposed to revise its December 2000 finding that regulating utilities under section 112 was necessary and appropriate.

[10] This approach would not require EPA to revise its December 2000 finding, but would require EPA to "de-list" utilities as a source category requiring a MACT standard.

obtain their views. We reviewed data and analyses developed in support of the rule, and public comments included in the rulemaking docket. We also reviewed related information provided by both EPA and non-EPA officials contacted.

The Government Accountability Office is conducting a review of technology-related issues for the proposed mercury rule, which is an important consideration in determining whether the MACT standard can be set at a level that is more stringent than the floor. The Government Accountability Office report was not available in December 2004 for consideration in the OIG report.

Limitations

Our evaluation was conducted and completed before the Agency had completed the rulemaking process. Accordingly, our observations and characterizations about the process reflect the status of the rulemaking process at the time we completed our review. Issuance of the final rule is planned for March 15, 2005, and the final rule may consider additional information or analyses not available at the time we completed our review. For example, EPA released a notice of data availability for the proposed Clean Air Mercury Rule on December 1, 2004. The notice requests additional public comment on issues addressed in this report, and solicits further comment on new data and information to help EPA evaluate which regulatory approach will best reduce mercury emissions from power plants. We did not specifically consider the notice because it was released after we had completed our review and analyses. However, the notice includes information available previously in the public comment docket for this rule, and it is possible we had considered some of that information during our review.

The OIG was not provided with several important documents it requested from the Agency; therefore, that information was not available for consideration in this report. Our memorandum detailing the requested information, as well as specifics on what information was provided by the Agency, are provided in Appendix B. Consideration of the inter-agency review process was limited to information from EPA staff and information available in the docket only. We were not able to discuss the inter-agency review process with Office of Management and Budget (OMB) staff who were responsible for coordinating the inter-agency review process. The OIG did not independently analyze the databases or computer modeling programs that EPA used in developing the proposed rule. With respect to the development of the MACT standard, the OIG did not attempt to independently calculate the MACT floor.

Results in Brief

Evidence indicates that EPA senior management instructed EPA staff to develop a MACT standard for mercury that would result in national emissions of 34 tons annually, instead of basing the standard on what the top performing units were achieving in practice. Also, we determined that EPA's mercury cap-and-trade proposal – a nationwide emissions trading program for an air toxic – can be strengthened to better ensure that human health is protected and anticipated emission reductions achieved, should this approach to reducing mercury emissions be adopted. Further, although EPA rulemaking procedures are not consistently applied, Agency staff told us that they would have expected greater adherence to the guidance for mercury rule development due to the significance of this particular regulatory action, but this did not happen.

We recommend that EPA re-analyze mercury emissions data collected, and conduct a revised cost-benefit analysis for the updated MACT that takes into account the impact of mercury co-benefits achieved through the proposed CAIR. We also recommend that the Agency strengthen its cap-and-trade proposal. Further, we recommend that the Agency conduct an integrated analysis with respect to whether emissions reductions under either of these proposals are the most child-protective, timely, and cost-effective.

The Agency disagreed with certain aspects of our draft report, and offered suggested changes or revisions. The Agency's response did not specifically address our recommendations. We made changes to the final report based on the Agency's comments, as appropriate. See Appendix E for the full text of the Agency's official comments to our draft report and our response to these comments.

Chapter 2
Mercury MACT Development Compromised

Evidence indicates that EPA senior management instructed EPA staff to develop a MACT standard for mercury that would result in national emissions of 34 tons annually, instead of basing the standard on an unbiased calculation of what the top performing units were achieving in practice. The CAA requires that a MACT standard should, at a minimum, be based on the emissions levels achieved by the top performing 12 percent of units, not a targeted national emissions result. The 34-tons-per-year target was based on the co-benefits expected to be achieved from implementation of NOx and SO_2 controls under the proposed CAIR. EPA noted that this target was based on extensive analysis and, in EPA's judgment, represented the lowest level of mercury emissions that it could reasonably expect the utility industry to achieve.

Because the results of the MACT standard were prescribed and prior estimates were lower than what was proposed, we believe it likely that the standard understates the average amount of mercury emissions reductions achieved by the top performing 12 percent of power units. Some Agency officials told us that, in their opinion, the true MACT floor would result in lower mercury emissions than the 34 tons estimated from current MACT floor limits. Therefore, if this proposed MACT standard was adopted, it would not achieve the maximum emission reductions achievable and the associated health benefits. Further, this MACT standard, as proposed, does not provide a reasonable basis for comparison in determining which of EPA's two proposed regulatory alternatives (i.e., the MACT standard or the mercury cap-and-trade program) provides the better cost-benefit.

Requirements for MACT Standards

In accordance with the CAA, EPA is to establish MACT standards that require the maximum emissions reductions the Agency believes are achievable for a major source category. At a minimum, the MACT standard cannot be less stringent than the average emission reductions achieved by the top performing 12 percent of units in a category (e.g., all coal-burning utilities) or subcategory (e.g., utilities burning bituminous coal) for which the Administrator has data. EPA has wide latitude in the types of emissions data used to determine the MACT floor, including the discretion to select a reasonable method to estimate emissions achieved, and to address variability to account for the most adverse operating conditions reasonably foreseeable. If EPA decides to set a limit beyond the floor, it must consider the cost of achieving those reductions, any resulting non-air quality and environmental impacts, and energy requirements.

In accordance with a court settlement, EPA had agreed to publish its final mercury rule by December 15, 2004. This date was re-negotiated with the court petitioner and the final rule deadline was extended to March 15, 2005.

EPA's Process for Addressing Variability in Computation of Mercury MACT Floor

As provided under CAA section 112(d), EPA first determined whether a MACT standard should be developed for all coal-fired units or sub-categories. EPA analyzed the ICR data and identified the top performing units from all units for which emissions data were collected. Evaluation of the ICR data for the top performing units focused on coal type, plant processes, and control technology. EPA could not identify a common attribute that contributed to mercury emission reductions for all of the top performing units that would allow development of a single MACT emissions limit for all units. Additionally, it was determined that no units had installed mercury-specific control technology, although controls installed to reduce emissions of other pollutants also helped reduce mercury emissions. When no single common factor was identified, EPA evaluated the data further and determined that sub-categorization by coal type, which is also a driving factor in plant design, was warranted to establish the MACT. One additional sub-category was established for a particular plant type – Integrated Gasification Combined Cycle – because the plant burns gas from coal rather than any particular type of coal.

For each sub-category, EPA identified the top performing units based on emission tests collected during the ICR. However, EPA determined that these emission tests alone did not sufficiently estimate the effect of fuel variability over time on the emissions of the best performing units. To account for this variability, EPA used coal composition data (i.e., mercury and chlorine content) for coal shipments collected during the ICR to estimate emissions throughout the year for the top performing units in each subcategory. This increased the number of emission points available from which to calculate the MACT limits. [11]

The emission points for each of the top performing units were ranked and then EPA selected one of the highest emissions points (i.e., the 97.5 percentile) for each unit. According to EPA, this emission point reflects the best performance under the worst foreseeable operating conditions for the unit. EPA took the average of these selected emission points for each sub-category and adjusted this

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[11] Prior court cases have upheld EPA's right to consider variability in developing MACT floors. For a discussion of the appropriateness of EPA's efforts to account for variability, see *Cement Kiln Recycling Coalition v. Envt'l Protection Agency*, 255 F.3d 855 (D.C.Cir. 2001), *examining, Sierra Club v. Envt'l Protection Agency,* 167 F.3d 658 (D.C.Cir.1999) and *National Lime Ass'n v. Envt'l Protection Agency*, 233 F.3d 625, 629 (D.C.Cir.2000) ("National Lime II").

average to further account for variability (i.e., the 97.5 percent upper confidence level of the average). This adjusted average was established as the MACT floor and the proposed standard for each subcategory.

Unlike many previous MACT standards, the proposed utility MACT standard would not require the installation of a specific control technology since no mercury-specific control technology had been installed in utilities. EPA determined that emerging mercury-specific technologies were not yet commercially available for the utility industry. The Government Accountability Office is conducting a study to assess the current state of mercury control technology.

EPA Staff Instructed to Develop MACT Floor That Would Result in National Emissions of 34 Tons

Evidence indicates that EPA staff were instructed to develop a MACT standard that would result in national emissions of 34 tons per year. Some staff told us that they heard these specific directions and others told us that they heard in different meetings during rule development that the application of the MACT floor to utilities should equal 34 tons per year (a 29-percent reduction from the present 48-tons emitted nationwide). These statements were further corroborated by internal EPA e-mails, which specifically identified 34 tons per year as the number desired despite the fact that prior modeling results did not result in 34 tons. E-mails between EPA staff discussed various MACT emission limits by subcategory and modeling scenarios that could be used to get closer to the 34 tons target. For example, a November 2003 e-mail stated that:

> *If the 14+K of subbit ACI is using the 90% option and we restrict this to 60%, perhaps we can get in the 34 tpy range. I don't think that restriction would be considered inappropriate for a 2007 MACT analysis.*

EPA documents and an analysis of the process used to compute the MACT floor support EPA staff's statements that the MACT floor computations were developed to produce the desired national emissions of 34 tons per year. Documentation that we reviewed indicated that EPA conducted at least three Integrated Planning Model (IPM)[12] runs in order to reach the pre-determined target for national mercury emissions of 34 tons. The initial IPM run to try to reach the 34-tons target yielded a national emission of 29 tons (i.e., the IPM model indicated that mercury could be reduced from 48 tons to 29 tons). After changing the proposed MACT emission limits, a second IPM model yielded a

[12] EPA uses ICF Resources Incorporated's Integrated Planning Model for air emission modeling. The model projects what decisions utilities would make for meeting air emission regulations based on economic considerations.

national emission of 27 tons. While we were provided summary information about these two IPM model runs, they were not included in the EPA rulemaking docket.

An Agency source indicated that these results were not acceptable to senior management because they were not close enough to the 34-tons target. A third run performed, based on the proposed emission limits, showed 31 tons. EPA cited the 31-tons model results in the proposed rule, but explained in the preamble that 34 tons is the more probable emissions level because the model used to estimate emissions was underestimating the amount of mercury emissions that would occur. EPA noted that the IPM model may have understated mercury emissions by 2.3 tons for units burning bituminous coal.[13] Table 2-1 depicts the emission limits used in the three IPM runs and the resulting total national emissions:

Table 2-1: Results of Proposed MACT Scenarios to Reach 34 Tons

Coal type	Run #1	Run #2	Run #3 (Proposal)
Bituminous	0.57 *	1.4 *	1.9679 *
Sub-bituminous	6.46 *	5.06 *	5.8 *
Lignite	18.45 *	19.48 *	9.2 *
Total National Mercury Emissions (tons-per-year)	29-30 **	27.2-27.9**	30-31**

* Proposed per unit mercury emission standard expressed in pounds per trillion British thermal units (lb/TBtu).

** Estimated tons of national mercury emission resulting from modeling the application of the unit emission standard to all utility units.

The emission limits shown in Run #3 above, ultimately proposed as the MACT standard, were based on a multi-variability analysis submitted by WEST Associates (a western utility consortium).[14] However, EPA adjusted this approach, increasing the MACT floor emission limits for two of the three subcategories beyond those derived by WEST Associates. For example, WEST Associates used an upper confidence level of 95 percent of the mean of the best performing units to account for variability. EPA adjusted the confidence level to

[13] The IPM model only allows Activated Carbon Injection technology, a mercury specific control technology, to reduce mercury emissions at 60% and 90% levels. The inability of the model to address the full range of reductions between these two levels means that the model may have understated mercury emissions by as much as 2.3 tons for bituminous-fired units.

[14] The analysis was submitted during the last Federal Advisory Committee Act meeting, convened in March 2003.

97.5 percent, which resulted in an increase in the emission limit for two of the three sub-categories. According to EPA's variability analysis, this adjustment was made to account for EPA's interpretation of the number of units that should be included in the MACT floor analysis.[15] These adjustments increased the MACT floor closer to a national emission level of 34 tons per year.

Relationship of the 34-Ton Estimate to Cap-and-Trade Proposals

The 34-tons-per-year target is important because it is based on mercury emission modeling results used in two separately proposed cap-and-trade programs for utilities – CAIR and the mercury cap-and-trade program – proposed as alternatives to the mercury MACT. EPA has stated its intent to implement its multi-pollutant (mercury, SO_2, and NOx) cap-and-trade programs, originally included in stalled Clear Skies legislation, through the proposed CAIR and mercury regulations.

EPA has also proposed that the mercury reductions gained from implementing CAIR should serve as the interim cap on mercury emissions in the mercury cap-and-trade program. According to the preamble to the mercury rule, the reason for basing the interim cap on the co-benefits from CAIR is that the Agency does not believe mercury control technology that has been demonstrated for all coal types is commercially available. In addition, Agency officials stated that the 34-tons-per-year target was based on the co-benefits expected to be achieved from implementation of NOx and SO_2 controls under the proposed CAIR. They noted that this target was based on extensive analysis and, in EPA's judgment, represents the lowest level of mercury emissions that they could reasonably expect this industry to achieve by 2010.

Additional Estimates of Mercury Emissions

Interviews with sources both inside and outside the Agency suggest that if unbiased analyses of data were conducted, a range of possible MACT floor levels would most likely result. One EPA official stated that the true range of possible MACT floors was probably as low as 8 to 10 tons per year up to the mid-20s, but that either end of that range would be a stretch. Further, the source stated that the real range is about 15 tons per year to the low 20s for this MACT, and that anything above or below those numbers was a stretch. This includes the 34 tons proposed by the Agency. These statements about the possible range of MACT floors are supported by results of different MACT floor limits and/or varying model assumptions used by some organizations providing comments to the

[15] For example, West Associates used 5 units for each sub-category, while EPA used 4 units for the bituminous and sub-bituminous sub-categories and 5 units for lignite sub-category.

proposed rule. For example, the Clean Air Task Force evaluated the ICR data to develop MACT floor limits that were different than those developed by EPA. Applying these limits to the same IPM model used by EPA resulted in national mercury emissions of 12 tons[16] (i.e., a 75-percent reduction from 48 tons). Modeling by the Electric Power Research Institute and Edison Electric Institute used the MACT floor limits proposed in the rule and showed an estimated 32 tons of mercury emissions nationwide (i.e., a 33-percent reduction from 48 tons). Examples of varying modeling efforts and results can be found in Appendix C.

Conclusions

EPA's current estimate of the amount of mercury emissions occurring after implementing SO_2 and NOx controls, called for in EPA's CAIR, is 34 tons. Given (1) that EPA is attempting to implement the Clear Skies multi-pollutant approach through regulation; (2) the numerous modeling runs conducted to determine national emission resulting from different MACT emission limits; (3) the adjustments made in the accounting for variability; (4) the statements of EPA officials involved in the rulemaking process; and (5) EPA e-mails reviewed, we believe EPA's approach for developing the MACT floor was compromised. Further, it is unlikely that an unbiased calculation of the MACT floor would produce emission limits that would result in estimated national mercury emissions of 34 tons per year (i.e., EPA's current estimate of the co-benefit of SO_2 and NOx proposed regulations).

Recommendations

We recommend that the Assistant Administrator for Air and Radiation:

2-1 Conduct an unbiased analysis of the mercury emissions data to establish a MACT floor in accordance with the requirements of CAA section 112(d).

2-2 Re-negotiate with the court petitioner for an extension of the final rulemaking deadline sufficient to solicit and accept public comments on the unbiased analysis of mercury emissions data in an open, public, and transparent manner.

Agency Comments and OIG Evaluation

The Agency commented that the draft report incorrectly characterized the calculation of the MACT standard, and that the Agency had calculated the MACT

[16] The Clean Air Task Force considered the effect of implementing the proposed CAIR rule on the mercury MACT. EPA did not consider the impact of implementing CAIR in its MACT modeling efforts. More information on this issue is found in Chapter 4 of this report.

floor in accordance with the requirements of CAA section 112(d). The Agency also maintained that its extensive work, including development of the proposed Clear Skies legislation, showed that, in the absence of immediately available mercury control technology, the mercury reductions as co-benefits of SO_2 and NOx controls represent the lowest level of mercury emissions that the Agency reasonably expects could be achieved. We believe our report accurately characterized the MACT development process. Our observations were based on review of supporting documentation related to MACT development, and interviews with Agency staff and stakeholders involved in the process, including State and local, environmental, and industry groups. Although the MACT floor was ostensibly based on data from the top performing 12 percent of units, this data was analyzed with a final target already in mind, i.e., 34 tons. While the Agency has conducted analysis to determine the co-benefit of SO_2 and NOx controls, we do not believe this meets the requirements of CAA section 112(d) in developing the MACT standard. The Agency's complete response to the draft report and our evaluation of its response are in Appendix E.

Chapter 3
Cap-and-Trade Option Can Be Strengthened

EPA's mercury cap-and-trade proposal – a nationwide emissions trading program for an air toxic – can be strengthened to better ensure that human health is protected and that anticipated emission reductions are achieved, should this approach to reducing mercury emissions be adopted. The cap-and-trade proposal could be strengthened by:

- Adequately addressing the potential for hot spots.
- Establishing an interim cap that would provide greater incentive for utilities to install mercury-specific control technology by 2010.
- Setting a reasonable safety valve provision.
- Clarifying conditions pertaining to exemptions for small emitting facilities.

These changes could help ensure that the proposed mercury cap-and-trade program obtains the desired emissions reductions in a timely manner.

EPA's Proposed Cap-and-Trade Approach

A cap-and-trade program could provide several benefits in terms of controlling emissions. Trading programs generally provide regulated units with more flexibility to meet overall emissions reductions than do conventional command-and-control approaches because a unit may apply whichever control method it finds to be most appropriate and cost-effective to meet emission limits. This flexibility serves to minimize overall control costs in the market. Furthermore, cap-and-trade programs can provide greater environmental certainty by establishing fixed national emissions caps that cannot be exceeded. However, a cap-and-trade program's environmental benefits will depend on the adequacy of the cap.

Under EPA's proposed mercury emissions trading program, units that cannot cost-effectively reduce emissions through controls may buy allowances from units that were able to reduce emissions beyond their established allowance limits and are willing to sell their extra allowances. Each unit is required to possess one emissions allowance per each ounce of mercury it emits. Units would be allowed to buy and sell credits among one another in a national emissions market. EPA's proposed cap-and-trade alternative proposes that the interim mercury emissions cap for 2010 be based on the amount of mercury reductions achieved solely as a co-benefit through implementation of SO_2 and NOx controls under the proposed CAIR. As noted in Chapter 2, EPA's latest estimate of the mercury benefit from implementing CAIR is 34 tons per year. The cap-and-trade proposal sets a final cap of 15 tons per year in 2018.

Proposed Cap-and Trade Program Needs to Further Address Certain Issues

The proposed cap-and-trade rule for mercury meets the three basic guiding principles of trading programs as defined by EPA: a cap on emissions, accountability, and simplicity of design and implementation. However, we identified four issues with EPA's mercury cap-and-trade proposal that need to be further addressed. Details follow on each issue.

Interim Cap Could Be Tightened to Force Earlier Development of Mercury-Specific Control Technology

Although EPA has not yet set a specific interim cap for 2010, the preamble to the proposed rule states that the interim cap will be based solely on the mercury emissions reductions achieved as co-benefits of regulating SO_2 and NOx under CAIR, estimated by EPA to be 34 tons. Thus, it would not be necessary for units to install mercury-specific controls in order to meet the 2010 interim cap, and this would limit the effectiveness of the regulation to force new technological advances in mercury control. If the interim cap under this proposal is set at 34 tons, utilities could delay consideration of installing new mercury-specific technology until meeting the more stringent cap in 2018 is imminent. However, according to EPA officials, if the banking provision of the cap-and-trade program operates as intended, some facilities would have the incentive to implement mercury-specific controls before 2018, which would reduce emissions beyond the interim cap level before the final cap becomes effective. EPA officials also pointed out that experience under other cap-and-trade programs has shown that the largest emitters are typically the first to reduce emissions and will generally achieve the greatest level of reductions. According to the preamble, the reason for basing the interim cap solely on the co-benefits from CAIR is that EPA does not believe mercury control technology that has been demonstrated for all coal types is commercially available.

Further, the proposed rule does not address what would happen under the cap-and-trade approach if CAIR is not implemented. Given that the 2010 cap is based solely on the co-benefits from CAIR, it is unclear what would occur under the proposed rule if CAIR is not implemented.

An EPA official stated that although some EPA staff indicated they would like to see analyses on different cap levels for comparison purposes, no such formal analyses were conducted. EPA conducted one IPM run based on an interim cap of 34 tons and a final cap of 15 tons (in conjunction with CAIR), but no runs were conducted using alternative caps for comparison. Clear Skies analyses were made available in the proposed mercury rule docket, and according to an EPA official the mercury cap-and-trade IPM run is comparable to the Clear Skies IPM runs. According to this EPA official, one such run of Clear Skies had a different interim

cap (26 tons) and this run, while not exactly matching the modeling conducted for the proposed mercury cap-and-trade program, provides an idea about the costs of an alternative mercury cap.

Potential for Hot Spots Not Fully Analyzed

EPA did not fully analyze the potential for hot spots (i.e., areas of elevated pollutant concentrations) to occur under its proposed cap-and-trade option. The potential for hot spot formation under the proposed cap-and-trade rule has generated a great deal of concern and debate among various stakeholders. Modeling and projecting the likelihood of hot spots under the proposed rule is made difficult by the relatively high degree of uncertainty involved with mercury transport and deposition patterns (i.e., when the airborne mercury is deposited onto the ground or into water bodies), particularly local or near-field deposition.

Further complicating efforts to use computer models to determine where mercury deposition will occur is the fact that three different chemical forms of mercury are emitted by utility units and each has varying deposition patterns. For example, oxidized and particulate mercury are more likely to deposit locally or regionally, while elemental mercury travels and is more global in nature. Although air emission-related hot spots are generally thought of in terms of high ambient air concentrations near a source, this is not the only consideration with mercury. The main health risk associated with mercury is not its ambient concentrations, but rather its deposition into water bodies and resulting bioaccumulation in fish. However, the connection between air emissions and levels of mercury ultimately found in fish tissue is not yet fully understood.

EPA's Clean Air Markets Division conducted a Proximity Analysis to determine "where, in relation to water bodies, emissions would occur" under the mercury emissions trading provision of the Clean Air Interstate Rule. However, as noted in the analysis, the issue of hot spots was not fully analyzed:

> *This examination of projected mercury emissions has significant limitations and does not constitute an analysis of "hotspots." Such an analysis of hotspots would, in part, necessitate detailed assessments of the atmospheric fate, transport, and deposition of mercury from power generating sources, and assessments of the potential population exposure to mercury contaminated fish in water bodies due to generating and other sources.*

Although EPA did not conduct the detailed assessment of hot spots described above, EPA stated in the preamble to the proposed rule that it does not expect hot spots to occur for several reasons, as follows:

- Modeling suggests that the largest emitters, which are more likely to produce local deposition, will be the first to implement control technology under a cap-and-trade approach and will reduce emissions by the largest amount.

- CAIR would result in implementation of control technologies for SO_2 and NOx that also provide the co-benefit of reducing emissions of the types of mercury (oxidized and particulate) that are likely to deposit locally.

- The Acid Rain program has not resulted in the formation of hot spots.

- States have "the ability to address local health-based concerns separate from the mercury cap-and-trade program requirements," and under the proposed State-administered program would "retain the power . . . to adopt stricter regulations to address local hot spots or other problems."

- The proposed final cap would be a 70-percent reduction in mercury emissions from current uncontrolled levels (from 48 to 15 tons).

However, potential problems arise with EPA's reasoning. For example, the Acid Rain program controls for SO_2 emissions, which are primarily deposited regionally and globally, not locally, while mercury can deposit locally as well as regionally and globally. Trading programs are generally thought to be most effective for pollutants that do not deposit locally. Further, the Acid Rain program co-exists with the National Ambient Air Quality Standards program, which has established a minimum level of air quality for SO_2, while no such minimum standards exist as a back-stop in the mercury cap-and-trade proposal. In addition, the Acid Rain program contains a provision stipulating that, in the case of delayed implementation due to litigation, a more conventional command-and-control approach would take effect, but the proposed cap-and-trade rule for mercury lacks a similar provision.

While the preamble to the proposed rule notes that individual States have the authority under section 111 to adopt stricter regulations than those set by EPA, it does not address whether States would have this same authority under a section 112 cap-and-trade program. Further, approximately one-third of States have laws limiting "the ability of their regulatory agencies to adopt regulations that are more stringent than any federal environmental regulation." Thus, these States may not be able to adequately address hot spots, should they arise.

EPA has recognized that additional information is needed to better understand and address potential hot spots. For example, in the preamble to the proposed rule, EPA states its intent to reassess the hot spot issue by taking a ". . . hard look at the Hg emissions inventory after full implementation of the first phase cap. . . ," and also requested comments on how it might address hot spots in a cap-and-trade program. In addition, EPA suggested the use of trading ratios between regions as

a way to address potential regional deposition differences. The Agency also requested site-specific data on areas where commenters believe hot spots would continue to exist if a cap-and-trade program were implemented.

Due to time constraints, the OIG did not fully evaluate potential environmental justice implications resulting from a cap-and-trade program, nor did we fully assess the extent of the Agency's analysis of these issues.

Safety Valve Provision May Not Encourage Reductions

The proposed safety valve price may be set too low to achieve the intended effect of reducing mercury emissions through the installation of control technology and the open-market trading of emission allowances. The safety valve provision in the proposed cap-and-trade mercury rule provides a price cap on the cost of emissions reductions, and was included in the proposed rule due to uncertainties associated with future costs and the availability of mercury control technologies. Under the safety valve provisions of the proposed rule, if the price of allowances reaches a certain level, units will be permitted to borrow allowances from the future for a fixed price. To help ensure that the overall cap on emissions is met over the long-term, units can borrow only from their own bank of future allowances. The provision is intended to "minimize unanticipated market volatility" and ensure that "the cost of control does not exceed a certain level." Thus, in effect, units may emit more in the current period, but would be forced to emit less in the future because they are using future allowances. However, we identified two concerns with the proposed safety valve provisions.

Safety Valve Price. For a safety valve provision to be used appropriately (that is, only when market volatility makes it necessary), the price should be set so that it is higher than the market price of allowances or the actual cost of abatement (emission reduction). If this price is too low, it may be cheaper for the unit operator to purchase future emissions allowance at the safety valve price rather than installing emission controls. Under the proposed rule, the safety valve price is set at $35,000 per pound, or $2,187.50 per ounce, adjusted annually for inflation. This figure was decided upon during development of the Clear Skies Initiative, but new analyses have estimated that the actual cost of abatement will be substantially higher than $35,000 per pound.

Although EPA stated in one of the rule's supporting documents that, "based on current technological capabilities, the cost of mercury removal is expected to reach the safety valve price ($35,000/lb) by 2010," it further stated that "technological improvements could decrease the cost of mercury control over time and cause prices to remain below safety valve levels." Staff within EPA indicated that the current safety valve price of $35,000 was too low based on new analyses. For example, 2003 and 2004 Department of Energy estimates show the "baseline costs" of mercury removal to be $50,000 - $75,000 per pound, with cost

reductions expected over time. However, senior EPA officials told us that they did not believe the safety valve price would be reached because they expect the cost of activated carbon injection, a mercury-specific control technology, to decrease over time. According to these officials, the IPM does not account for this variable and may be misleading since it shows the cost of activated carbon injection remaining constant over time.

Safety Valve Borrowing. The proposed rule stated that units may purchase safety valve allowances from "following years," and the supplemental notice stated they may be purchased from allowances available for allocation in the next control period. The supplemental notice also provided an example of how a State could incorporate the safety valve provision into its cap-and-trade program. However, the proposed safety valve provision does not place a limit on the number of allowances a unit can borrow under this provision. As the Clean Air Task Force writes in its comments, a unit could, theoretically, continue borrowing indefinitely from future years by buying safety valve allowances in lieu of installing controls or buying allowances on the open market. Such an approach would make economic sense as long as the proposed safety valve price was set lower than the baseline cost of controls. In the proposed rule, EPA acknowledges that its "proposed approach may create implementation problems associated with the need to 'reconcile' at some point in time the allowances borrowed from future compliance periods," and requests comment on the issue.

Small Emitters Exemption Needs To Be Clarified

EPA has proposed that utility units emitting less than 25 pounds of mercury per year be exempt from the cap-and-trade program, but has not completely addressed how their exemption and the national emission cap will be impacted if their emissions increase. EPA included this exemption because of concerns that new mercury-specific control technologies expected to be developed may not practicably apply to these units. Based on EPA data developed for units operational in 1999, 396 of the 1,120 units operational in 1999 were estimated to have emitted less than 25 pounds of mercury per year each. These 396 units made up 35.4 percent of the total operating units, but contributed only 3,742 of the 95,975 pounds of estimated mercury emissions, or 3.9 percent in 1999. According to the proposed rule's preamble, EPA states there is reason to believe that the 15-tons Phase II cap can be achieved in a cost effective manner, even if the lowest emitting 396 units are excluded from coverage under this cap. EPA is soliciting comment on this proposal.

One commenter noted that both capacity utilization and emission rate increases could occur in small emitting sources after they have been exempted from cap-and-trade requirements. EPA does not address this issue in the proposed rule. Another commenter stated that EPA had done no analysis of the small emitter exemption with respect to either costs or impacts. According to this commenter, a

vast majority of the units emitting less than 25 pounds of mercury are part of a multi-boiler facility, and it is entirely likely that at some facilities all of the boilers are tied into common duct work for pollution control. Consequently, these units should be considered as one unit emitting over 25 pounds and not eligible for the exemption.

While we did not fully assess the impact of this, we believe the commenters have raised valid concerns. Further, we noted that the relative significance of these small emitters increases as the cap-and-trade program progresses. For example, in 2018, these emitters, based on their 1999 emissions, would represent 12.5 percent of the total 15 tons in emissions allowed under the final cap. If EPA moves forward with its cap-and-trade proposal, the Agency can better ensure that anticipated emission reductions are achieved if it clearly addresses the circumstances under which small emitters would have to participate in the cap-and-trade program.

Proposed Emissions Trading Rule Should Also Address Tribal Concerns

Although Executive Order 13175 requires EPA to develop an "accountable process to ensure meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications,"[17] tribal concerns were not addressed during development of the proposed cap-and-trade rule. In the preamble, EPA states that the proposed rule may have tribal implications because two coal-fired utility units are located in Indian Country. Representatives from the National Tribal Environmental Council (NTEC) informed us that neither they nor their approximately 180 member tribes had any involvement in the development of the proposed mercury rule. This was confirmed by an EPA official at a March 2004 public meeting on the proposed mercury rule.

Among NTEC's greatest concerns over the proposed mercury rule are:

- the absence of tribal involvement and/or consultation in the development of the proposal;
- a failure to adequately monitor mercury deposition on tribal lands, which means that the impact of mercury is unknown; and
- lack of consideration for American Indians and Alaska Natives' dependence upon fish and the terrestrial animals that feed on those local fish.

The average tribal member and child eats much more fish than the typical consumer and the representatives explained that tribes (especially children and the expanding youth population) are faced with increased adverse health effects

[17] Consultation and Coordination with Indian Tribal Governments (65 FR 67249, November 6, 2000).

caused by such exposure.

NTEC does not support the cap-and-trade program and noted that, if the program is implemented, there is no mechanism currently in place for the tribes to enter into cap-and-trade allowance sales. In fact, allowances are only available to the States. NTEC cited the U.S. Government's trust responsibility, which includes looking after the health and survival of tribes. This responsibility is met in part by conducting tribal consultation on a government-to-government basis.

EPA officials noted that other organizations, including States, were not consulted during the development of the cap-and-trade proposal. Although States were not consulted, we noted that States were allotted mercury allowances while the Tribes were not.

Conclusions

The cap-and-trade proposal can be strengthened to better ensure that the anticipated emission reductions are achieved, should this approach be adopted by EPA. First, the interim cap suggested under the current proposal is set at a level that could be met without installing mercury-specific control technology, thus potentially delaying installation of mercury-specific controls until 2018. Also, the cap-and-trade option has not adequately addressed the potential for hot spots. In addition, EPA needs to ensure that it establishes a safety valve provision that will have the intended effect of encouraging unit operators to install controls or buy emission credits. Further, EPA needs to ensure adequate tribal involvement for the proposed mercury rule to ensure that tribes are not negatively impacted by a cap-and-trade rule.

Recommendations

We recommend that the Assistant Administrator for Air and Radiation:

3-1 Re-assess the basis for the interim and final caps. This analysis should consider the results of the re-assessed MACT floor (see Recommendation 2-1).

3-2 Further assess the risk of hot spots and, if CAA section 112 residual risk requirements are not implemented, then section 111 cap-and-trade regulations should specifically identify how EPA will meet its intention to reassess the hot spots issue.

3-3 Strengthen the safety valve provision so that the safety valve price is set at a level whereby it is only used for its intended purpose of minimizing unanticipated market volatility. Alternatively, EPA may stipulate other

controls over borrowing from future allowances, such as imposing a greater than 1:1 allowance trading ratio; and allowances borrowed from the future will be reconciled to ensure that facilities cannot borrow indefinitely into the future.

3-4 Reassess the necessity of a small emitter exemption, and if a decision is made to exempt, explain in sufficient detail the reasoning for such a provision and establish how small emitters will be handled within the cap-and-trade program should they exceed emissions of 25 pounds a year.

3-5 Address tribal issues by: developing a mercury emissions consultation strategy with tribes, with the assistance of tribal representatives, that will ensure the Agency fulfills its trust responsibility and conducts proper government-to-government consultation with tribes; and establishing a mechanism for coal-fired utilities located on tribal lands to participate in the cap-and-trade approach.

Agency Comments and OIG Evaluation

The Agency's comments expressed a concern that the report does not "comprehensively and accurately describe" how the proposed cap-and-trade approach would work. The Agency also expressed concern that we did not highlight the knowledge EPA has gained from modeling and past experience with cap-and-trade programs. We believe our draft report portrayed an accurate representation of how the proposed mercury cap-and-trade program would work. One of the objectives of our review was to evaluate whether the proposed cap and trade rule was sufficiently protective of public health. As a result, we highlighted certain concerns with the rule as proposed. We made revisions, where appropriate, based on technical comments made by Agency staff and officials. However, there are several important differences between the Acid Rain program, to which the Agency often refers when discussing past cap-and-trade experience, and the proposed mercury cap-and-trade program. The Agency's complete response to the draft report and our evaluation of its response are in Appendix E.

Chapter 4
Rule Development Process Not Consistent with Expected and Past Practices

Although EPA rulemaking procedures are not always applied consistently, many Agency staff told us that they would have expected greater adherence to the guidance for mercury rule development due to the significance of this particular regulatory action, but this did not happen. When the Clear Skies legislation stalled, EPA decided to address the Clear Skies program in a regulatory manner instead. This led to EPA including a mercury cap-and-trade option, similar to Clear Skies, in its proposed mercury rule. As focus on the cap-and-trade approach increased, EPA began to de-emphasize the mercury MACT development process. This included:

- Cancelling the next scheduled Federal Advisory Committee Act (FACA) meeting and ending communication with FACA members.
- Abridging the normal intra-agency review process, particularly at the staff level.
- Failing to fully address the cost-benefit of MACT alternatives and not analyzing the potential impact of implementing CAIR on the proposed MACT option.
- Not fully analyzing the impact of the proposed mercury cap-and-trade program on children's health.

Description of Rulemaking Process

EPA's Action Development Process: Guidance for EPA staff on Developing Quality Actions outlines steps EPA staff and management are to follow when developing Agency actions, such as rules, policy statements, and statutorily mandated reports to Congress. The guidance suggests that EPA staff follow a prescribed set of steps beginning with tiering the action based on several of its characteristics. Once tiered, a standard process exists for developing the proposed action. As a Tier One action, the proposed mercury utility rule was considered a top action that would ". . . demand the ongoing involvement of the Administrator's office and extensive cross-Agency involvement on the part of the AAs/RAs (Assistant Administrators and Regional Administrators)."

The Action Development Process guidance contains five key elements, which are summarized below. These include steps for:

- planning sound scientific and economic analysis;

- developing and selecting regulatory options based on relevant scientific, economic, and policy analyses;
- involving affected Headquarters and Regional managers early and continuing involvement until the final action is completed;
- ensuring active and appropriate cross-Agency participation; and
- encouraging appropriate and meaningful consultation with stakeholders through substantive consultative procedures.

Appendix D describes the rule development process in detail.

Some FACA Members Considered Job Unfinished

Within EPA, the creation of an advisory committee is not required for MACT rule developments, but such groups have been formed to advise the Agency in past MACT rulemakings and can provide a means of substantive consultation with stakeholders. An EPA official noted that for contentious rulemakings where a great deal of stakeholder involvement and public comment is anticipated, such as the mercury rule, it is not uncommon for an advisory committee to be formed. FACA allows for the creation of committees, boards, commissions, councils, and similar groups to furnish expert advice, ideas, and diverse opinions to officers and agencies in the executive branch of the Federal Government. The Act notes that the function of committees is advisory only, and decisions on how the advice will be used is determined by the official, agency, or officer involved.

The FACA working group for this rulemaking, known as the Utility MACT working group, was formed within the Permits/New Source Review Air Toxics Subcommittee of the larger Clean Air Act Advisory Committee. Working group members consisted of representatives from State and local agencies; environmental organizations; industry; control equipment vendors; and coal interests, producers, and unions. Both co-chairs of the group indicated that they believed the working group had balanced stakeholder representation.[18] The working group was formed for an initial period of 1 year and met approximately once per month starting August 2001.

The working group was charged with providing input for the development of a MACT standard for utilities. In a presentation given to the group by the EPA co-chair, the group was instructed that they were not to reconsider the Agency's prior finding that regulation of coal-fired electric steam generating units under section 112 of the CAA was necessary and appropriate, nor were they to consider a cap-and-trade option. Although a cap-and-trade option was introduced in Congress in July 2002 in the Clear Skies legislation, this option was not considered by the working group.

[18] Although the working group did not include tribal representation, EPA solicited their participation.

In October 2002, the working group issued its final report, *Recommendations for the Utility Air Toxics MACT: Final Working Group Report,* in which it identified issues that "EPA must consider and resolve in its drafting of the utility MACT." Some of the issues identified included:

- sub-categories;
- floor levels;
- beyond-the-floor levels of mercury;
- compliance method (monitoring); and
- compliance time.

The working group decided early that consensus among its various stakeholder groups was unlikely, and did not attempt to reach agreement on specific recommendations it could make to the Agency. Instead, the report presented the opinions of all the stakeholders on the issues.

Though the working group issued the final report in October 2002, it held another meeting on March 4, 2003, just after Clear Skies legislation was re-proposed in February. Certain members of the working group had requested that EPA conduct additional analyses using the IPM to further explore the cost-benefit of different MACT proposals as presented by the working group members. Members of the working group did not have direct access to the IPM, as EPA contracts for its use through a third party, and thus requested that EPA have the additional analyses run and then provide the group with the results. According to several members of the working group we contacted, it was expected that the working group would receive the results of the additionally requested IPM runs at the March 4 meeting, but were instead told the runs were not yet complete. Another meeting was scheduled for April 15, 2003, to provide the results of the IPM runs, but members were notified by EPA of its cancellation via e-mail on April 1.

In July 2003, Administrator Whitman responded to Congressman Waxman's request for the status of IPM runs for the working group. The Administrator stated that it was the Agency's intention to convene an additional FACA meeting when the IPM analyses were complete. However, in March 2004, the Assistant Administrator for Air and Radiation said the Agency would not provide the additional MACT IPM analyses and would instead focus resources on developing a cap-and-trade alternative, the administration's preferred regulatory approach.

The working group has not met since its last meeting in March 2003 and has not been officially contacted by the Agency since its planned April 15, 2003, meeting was cancelled. A formal notice of termination has not been issued to the working group and, according to some members, they were not given an explanation as to why the working group ended. EPA has stated on its web site that it began proceeding with a cap-and-trade regulatory approach in the absence of Congressional action on Clear Skies legislation. The FACA working group's

deliberations were stopped after Clear Skies was re-proposed and before EPA began developing its proposed cap-and-trade regulation. While some working group members indicated satisfaction with the work completed by the group, others considered the job unfinished due to the lack of opportunity to consider the additionally requested runs.

According to senior EPA officials, the working group's original charter was for only one year. One of the officials acknowledged that EPA had initially intended to conduct the runs requested by the working group but later decided that it would not be beneficial. These officials further indicated that since the working group had not reached consensus, the Agency did not believe the working group should have been extended.

Intra-Agency Review Limited

According to staff involved, the intra-agency work group review process followed in this rulemaking varied significantly from past Agency practice and applicable guidance for Tier One rules in that the group only met two times and was not given an opportunity to provide meaningful feedback on the proposed rule. According to the Agency's regulatory development guidance, a work group is to meet frequently enough to ensure that all significant issues and options are discussed and agreed upon. Then, the significant issues and several options to resolve each issue are to be provided to senior management. Senior management then selects those options they believe will best achieve the goals of the action for a Final Agency Review.

The work group's first meeting was held on February 27, 2003, and the second and final meeting took place on August 7, 2004. In preparation for the first meeting, the work group chair e-mailed to the work group members a copy of the Utility MACT FACA working group's final report, along with a draft analytical blueprint for the rulemaking. According to EPA's Action Development Plan, an analytical blueprint is "a document that spells out a work group's plans for data collection and analyses that will support development of a specific action," and is intended to be developed as "a collaborative effort." The draft blueprint stated, "the intent of the rule is to require that oil-and-coal-fired units achieve a MACT-level of control," and it listed the "minimum analytical needs" for the rulemaking:

- A regulatory impact analysis, assessing the economic impact on industry of levels beyond the MACT floor.
- Assessment of multi-pathway concerns.
- A regulatory flexibility analysis addressing small business concerns.
- Assessment of environmental justice concerns.
- Children's health concerns.
- Unfunded mandate assessment, evaluating the impact of the rulemaking on State/local/tribal governments, some of which own or operate coal-fired units.

- ICR issues.

Although the above issues were identified for study in the draft analytical blueprint, some were never fully addressed, such as the children's health study and an assessment of environmental justice concerns. The draft blueprint also stated that:

> *". . . the EPA believes that emissions trading is prohibited under Section 112 of the CAA. However, industry, and to a more limited extent, some other stakeholders would like to explore emissions trading as an option (perhaps in beyond-the-floor analyses) for this rulemaking."*

Members of the work group, including the Office of Research and Development and the Office of Policy, Economics, and Innovation, submitted comments to the draft analytical blueprint via e-mail to the work group chair. But work group participants we interviewed stated that they received no feedback or modified drafts of any work products based on their comments and input.

In preparation for the second intra-agency workgroup meeting, members were asked to review and comment on four sections (approximately 42 pages) of an early version of the draft (July 3, 2003) preamble. However, intra-agency workgroup members received no modified work products that incorporated their feedback. Additionally, no Final Agency Review meeting was held for the proposed mercury rule whereby core intra-agency review participants had the opportunity to concur or nonconcur with the proposed rule before it was sent to OMB for review and final action.

Several EPA staff who were involved in the abbreviated intra-agency work group review process told the OIG that it was made clear to them by their managers, and in the case of one work group representative, by the work group chair, that decisions about this rule were being made at a "higher level." For example, in an e-mail discussing intra-agency comments, a member of the work group was told:

> *The decision was made at a much higher level than mine to "bypass" the normal EPA Work Group procedure prior to the proposal and we have been told that all the Office directors were contacted about both the process change and rulemaking.*

Similarly, these officials told us that it became clear to members that their feedback would not likely be considered. One Agency source said that, in general, there was not a meaningful opportunity for EPA offices to comment on this rule. Some Agency officials said they considered the intra-agency review process to have been conducted, but at a higher staff level and with less input than usual from lower staff levels. However, at least one office usually involved in the intra-agency review process – the Office of Enforcement and Compliance

Assurance – was neither given the opportunity to review nor submit comments regarding the proposed rule before it was sent to OMB, according to former and current Office of Enforcement and Compliance Assurance officials contacted.

According to senior EPA officials it is not unusual during the development of high-profile rules, particularly those under a tight deadline, for EPA to not strictly follow the Agency's prescribed rulemaking process.

Requirements for Cost-Benefit Analyses Not Fully Implemented

Although EPA conducted certain required analyses, other analyses were not completed. For rulemakings with an annual economic impact of $100 million or more, Executive Order 12866[19] requires that Federal agencies, in deciding whether or how to regulate, assess all costs and benefits of available regulatory alternatives and provide the reasoning for selecting the proposed regulatory action over such alternatives. This Executive Order also directs that Federal agencies base their decisions on the best reasonably obtainable scientific, technical, and economic information concerning the need for, and consequences of, the intended regulation.

EPA staff told OIG that senior management instructed them not to undertake certain scientific and technical analyses that they thought necessary. For example, staff were instructed during meetings not to conduct IPM runs (which could have been helpful in considering alternatives) until they were told the national mercury emissions per year desired for the MACT. As discussed in Chapter 2, EPA conducted analyses of various MACT floor levels, but presented only a 34-tons-per-year option to the public. In addition, the Agency did not fully analyze a beyond-the-floor MACT alternative.

EPA's cost-benefit analysis of the MACT proposal did not take into account mercury emissions reductions that would be gained as co-benefits resulting from NOx and SO_2 controls installed under the proposed CAIR. However, the Agency's cost-benefit analysis of the cap-and-trade option did consider CAIR co-benefits. This prevents a balanced comparison of the two options. EPA staff told us that a MACT-plus-CAIR alternative was not analyzed because, when the MACT floor was completed, CAIR had not yet been proposed. However, EPA issued a December 2004 Notice of Data Availability for the proposed rule, which included an analysis submitted by the Clean Air Task Force that estimates the impact (in terms of emission reductions) of CAIR in conjunction with the proposed MACT standard. The notice did not include a similar analysis by EPA.

The Agency did not monetize the health benefits of mercury reductions, though

[19] Regulatory Planning and Review, 58 FR 51735, October 4, 1993.

Office of Air and Radiation staff have said the final rule will include quantitative, non-monetized endpoints as well as a qualitative discussion. EPA staff told us that they have ongoing efforts to develop a benefits analysis, but that it is slow moving and has not been completed. Since March 2004, when the Administrator stated the Agency would take a closer look at the issue, there has been a process to try and do a full benefits analysis, but the process is moving slowly. While a benefits analysis should be based on scientific literature, staff told us that there had been pressure to base the analysis on public comment through the Notice of Data Availability. The notice presents a methodology for determining the benefit of mercury reductions and requests comment on this methodology.

Required Children's Health Analysis Not Comprehensive

EPA did not adequately evaluate the environmental health effects of the proposed rule on children. Executive Order 13045[20] requires such an evaluation because "[a] growing body of scientific knowledge demonstrates that children may suffer disproportionately from environmental health risks and safety risks." In prior MACT rulemakings EPA had determined that Executive Order 13045 and, therefore, a children's health evaluation, is not applicable because MACTs are technology standards and apply consistently to covered sources. However, since the proposed rule includes a cap-and-trade option, which is a performance standard that could result in an uneven distribution of emissions, it is covered under Executive Order 13045 and, therefore, an analysis of the rule's impact on children's health is required.

Although the proposed rule states that EPA evaluated health and safety effects pertaining to children, our review of the proposal and docket did not show that EPA performed such analyses in accordance with Executive Order 13045. We requested such analyses from EPA, but were not provided with any specific studies of the rule's impact on children's health. Interviews with officials from EPA's Office of Children's Health Protection indicated they were not involved during the rule development. However, Office of Children's Health Protection staff said their lack of involvement in such functions is not unusual due to limited staffing.[21] Members of the Children's Health Protection Advisory Committee (CHPAC) told us that the proposed rule does not adequately take into account children's vulnerabilities. The CHPAC outlined their concerns in a January 26, 2004 letter to the Administrator, in which they made several recommendations, including that the Agency "[e]valuate the possibility that hot spots could result".

[20] Protection of Children From Environmental Health Risks and Safety Risks, 62 FR 19885, April 23, 1997.

[21] A May 2004 OIG report found that there was no overall, coordinated strategy integrating children's environmental health efforts into the Agency as a whole (*The Effectiveness of the Office of Children's Health Protection Cannot Yet Be Determined Quantitatively*; OIG Report No. 2004-P-00016; May 17, 2004).

from the cap-and-trade program as proposed.[22] In a subsequent June 8, 2004 letter to the Administrator, CHPAC additionally recommended that EPA "[e]valuate the relative health benefits of reducing mercury exposure for children and women of child-bearing age under the MACT and cap-and-trade regulatory options."

EPA senior officials noted that prior studies on the health impact of mercury addressed the impact of methylmercury exposure on children and, therefore, the rule itself addresses children's health. We recognize that current reference dose levels for mercury exposure are based on the impact to children's health. However, we were not provided any analyses assessing the extent to which the proposed rule may result in uneven distribution of mercury deposition that could increase some children's exposure to mercury. Office of Research and Development officials noted that regardless of the extent of any additional analysis, they do not know what the impact of reducing sources emissions by a certain percentage would have on deposition or in what timeframe. However, they noted that reductions in emissions will reduce atmospheric mercury, which in turn will result in less deposition, lower mercury levels in fish, and ultimately reductions in human exposure to mercury. EPA officials stated that this type of extensive analysis had not been done for the proposed rule, but they hoped to have a more detailed assessment for the final rule. They further explained that the Notice of Data Availability issued in December 2004 proposed a process for quantifying the proposed rule's impact on mercury deposition and the resulting bioaccumulation in the environment.

Scope Limitation: Inter-Agency Review

Due to time constraints[23] and the fact that OMB controls this process and not EPA, the OIG did not evaluate the inter-agency review process and EPA's response to the edits resulting from that process. The inter-agency review process occurs under the direction of OMB after a proposed rule is submitted to the Office of Information and Regulatory Affairs in OMB for review, as stipulated in Executive Order 12866. The process is typically informal and, according to one EPA official, details on the meetings between OMB and other agencies, as well as comments submitted to OMB during the review, often are not included in the formal docket.

It is difficult to determine every agency involved in the editing process, which agency made specific edits to the proposal, or the timing of these edits based on inter-agency review documents contained in the docket. We identified comments from at least four agencies or offices other than EPA and OMB: the Department

[22] Chapter 3 of this report recommends that EPA further assess the risk of hot spots.

[23] Our field work in some areas was limited in order to provide the results of our review to EPA management in time for them to consider our recommendations in developing the final rule.

of Energy; the Department of the Interior; the Small Business Administration; and the Council on Environmental Quality.

Conclusions

The rulemaking process did not meet the expectations of some EPA staff and FACA work group members, and did not fully address certain Executive Order requirements to conduct cost-benefit and children's health analyses. These deviations from prior practice and Executive Order requirements appeared to have occurred, in part, because of the Agency's decision to include a proposed cap-and-trade option in the proposed rule, as well as a need to meet the deadlines for the proposed MACT rule reached in prior court settlements.

Recommendations

We recommend that the Assistant Administrator for Air and Radiation:

4-1 Ensure that the Office adheres to the Action Development Process during EPA's future rulemaking actions to include obtaining input from all relevant Agency Offices.

4-2 Conduct more in-depth cost-benefit analyses of the proposed mercury options to determine the preferred approach.

4-3 Conduct a more in-depth analysis of the impact of the proposed options on children's health.

Agency Comments and OIG Evaluation

The Agency stated that the draft report failed to recognize the nature of the regulatory development process and incorrectly stated that EPA did not adequately evaluate the proposed rule's impact on children's health. Further, the Agency stated that the draft report improperly characterized the process by suggesting that it had not been sufficiently inclusive. We believe the draft report accurately described the rulemaking process, and continue to believe that the Agency should have more comprehensively evaluated the proposed cap-and-trade rule's impact on children's health. A cap-and-trade program, while reducing overall emissions, can result in geographically uneven distributions of emissions. The proposed rule did not include an analysis of where or how likely such varying mercury emissions and resulting depositions could occur, and what impact this may have on children's health. The OIG does not agree that the Agency review process was inclusive. As we noted in our draft report, according to staff involved, the intra-agency work group review process followed in this rulemaking varied significantly from past Agency practice and applicable guidance for Tier

One rules. Given this rule's far-reaching national implications for human health, the environment, and the economy, the OIG believes it was important for the Agency to have been more inclusive of available Agency expertise and external stakeholder input to develop this rule. The Agency's complete response to the draft report and our evaluation of its response are in Appendix E.

Appendix A

Timeline of Events Related to Development of Mercury Rule

Date	Event
November 15, 1990	President signs CAA Amendments of 1990. Section 112 requires EPA studies of mercury and Hazardous Air Pollutant emissions from utilities.
December 1997	EPA issues "Mercury Study Report to Congress." Emissions trading discussed as a control option.
February 1998	EPA issues "Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units." Defers decision on whether regulation of utilities is necessary and appropriate under CAA section 112.
July 11, 2000	National Academy of Sciences releases report, "Toxicological Effects of Methylmercury," which concludes that EPA's reference dose for methylmercury is a scientifically defensible level. Estimates that 60,000 newborns a year could experience neurological damage due to mercury.
December 2000	EPA Issues Federal Register Notice making final determination that regulation of mercury from utilities under CAA section 112 is "appropriate and necessary." Discusses cap-and-trade as an option but states that such an approach must protect local populations close to a source.
August 1, 2001	First meeting of Utility MACT working group. Charge to the Group is to develop a MACT standard. Explicitly directed not to consider trading.
July 2002	Clear Skies Act of 2002 introduced in the Senate and House of Representatives. Proposed a multi-pollutant approach to controlling SO_2, NOx, and mercury emissions from power plants.
August 28, 2002	EPA contractor memo outlines options for developing proposed MACT floor.
October 2002	Utility MACT working group issues final report. Consensus not reached. Additional IPM runs recommended based on MACT emission limit proposals from stakeholder groups.
February 27, 2003	Initial meeting of intra-agency work group (one of two total meetings). Analytical blueprint prepared for group addresses traditional MACT, not cap-and-trade, and identifies minimum analyses needed.
February 27, 2003	Clear Skies re-introduced in House and Senate as Clear Skies Act of 2003.
March 4, 2003	WEST Associates issues white paper proposing multi-variability method for determining MACT floor; presented at last meeting of Utility MACT working group. Paper presented to FACA at its last meeting. Method eventually adopted by EPA but with some changes.
March 4, 2003	Last meeting of Utility MACT working group. April meeting canceled by EPA; group had planned to discuss results of recommended IPM runs.
March 14, 2003	Briefing provided to Administrator Whitman. Presentation states EPA will continue to develop a section 112 MACT standard unless Congress removes the requirement.

Date	Event
April 1, 2003	EPA cancelled last FACA working group meeting. E-mail indicates runs not yet available, and meeting would be rescheduled at a later date.
August 7, 2003	Second (and final) intra-agency work group meeting held, reviewing draft preambles. Several MACT emission limits proposed, none of which match those in published proposed rule.
November 4-5, 2003	E-mails between EPA officials discuss efforts to establish MACT floor resulting in mercury emissions of 34 tons per year, based on IPM runs using various proposed MACT emission limits.
November 26, 2003	EPA memo to file explaining MACT floor (based on WEST Associates method).
December 15, 2003	"Regulatory Flexibility Act Analysis" entered in Docket.
December 2003	EPA contractor issued memorandum discussing beyond-the-floor analysis.
December 15, 2003	Proposed mercury rule signed.
January 2004	EPA Report on Benefit Analysis entered in Docket.
January 28, 2004	"Energy and Economic Impact Analysis" entered in Docket.
January 30, 2004	Proposed mercury rule published in the Federal Register.
March 16, 2004	Supplemental Notice issued to the original proposed rule providing procedures for implementing cap-and-trade proposal.

OIG's Request for Documents Related to Development of Utility MACT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF INSPECTOR GENERAL
OFFICE OF PROGRAM EVALUATION
1301 CONSTITUTION AVENUE, N.W.(2460T)
EPA WEST BUILDING
WASHINGTON, DC 20004

November 15, 2004

MEMORANDUM

Subject: Document Request for Assignment Number 2004-1021 - Development of the Proposed MACT for Utility Units

To: Jeffrey Holmstead,
Assistant Administrator for Air and Radiation

From: Kwai Chan, /s/
Assistant Inspector General for Program Evaluation

This memorandum is a formal request to you and your staff cc'ed below for several documents that we need in order to complete our work on the subject evaluation. The majority of these documents have already been requested and are listed again herein. In addition, we are requesting specific information (see item 7 below) not previously requested that is needed for us to fully and comprehensively address our evaluation objectives. We request that you provide us with the following information by November 26, 2004, in order that this information can be fully considered in our review:

1. Any and all statistical analysis and related internal correspondence for the two MACT IPM runs conducted in November 2003, including electronic records, that are not included in the docket.
2. Any and all written OGC analysis concerning use of Section 111 vs. Section 112, both for the December 2000 findings and determination and the January 2004 proposed rule, including electronic records.
3. Any and all documentation showing final intra-agency concurrence (or equivalent)

for issuing the proposed rule, including electronic records.

4. Any and all written comments resulting from the intra-agency review process, including electronic records.
5. The analysis related to children's health that was specifically referred to in the proposed rule's preamble on page 4715 of the Federal Register Notice.
6. The Agency analysis determining the origination of Latham and Watkins language that was included in the proposed rule's preamble, and
7. Any and all internal and external Agency correspondence or other written communications related to the development of the MACT floor that were developed, transmitted, and/or received during the period October 15, 2003 through December 15, 2003, including e-mails meeting the definition of Federal Records.

We appreciate your prompt response to this request. Please contact Jim Hatfield, Assignment Manager, at 919-541-1030, or Carolyn Blair, Project Manager, at 919-541-7702, to coordinate the submittal of information related to this request. If any of the above information does not exist please indicate that fact in your response.

cc: Robert Brenner, Deputy Assistant Administrator for Air and Radiation
Bill Wehrum, Office of the AA for OAR
Jason Burnett, Office of the AA for OAR
Stephen Page, Director, OAQPS
Sally Shaver, Director, Emissions Standards Division, OAQPS
Bob Wayland, Combustion Group Leader, ESD, OAQPS
William Maxwell, Principal Rulemaking Contact, Proposed MACT for Utility Units, ESD,
Nikki Tinsley, Inspector General
Eileen McMahon, Assistant Inspector General for Congressional and Public Liaison
Mark Bialek, Counsel, OIG

Status of Agency's Response to OIG's Request for Documents Related to Development of Utility MACT

Item Requested	*Status*
1. Any and all statistical analysis and related internal correspondence for the two MACT IPM runs conducted in November 2003, including electronic records, that are not included in the docket.	1. We received limited information after the draft report was provided to the Agency for comment. Specifically, we were provided copies of Agency e-mails that discussed how the information used in these MACT IPM runs was developed.
2. Any and all written OGC analysis concerning use of Section 111 vs. Section 112, both for the December 2000 findings and determination and the January 2004 proposed rule, including electronic records.	2. Since this was a legal issue before the courts, we determined that we would not address this, so the information was not needed.
3. Any and all documentation showing final intra-agency concurrence (or equivalent) for issuing the proposed rule, including electronic records.	3. No documentation provided.
4. Any and all written comments resulting from the intra-agency review process, including electronic records.	4. No documentation provided.
5. The analysis related to children's health that was specifically referred to in the proposed rule's preamble on page 4715 of the Federal Register Notice.	5. Additional information in general was provided after the draft report was issued, but no analysis on children's health specific to this rule was included.
6. The Agency analysis determining the origination of Latham and Watkins language that was included in the proposed rule's preamble, and	6. The Agency pointed out the information in the docket related to this issue, but did not provide specific Agency analysis. Since this issue was related to inter-agency review process, which is controlled by OMB, we did not fully address this issue (See Scope Limitation in Chapter 4 of this report.)

7. Any and all internal and external Agency correspondence or other written communications related to the development of the MACT floor that were developed, transmitted, and/or received during the period October 15, 2003 through December 15, 2003, including e-mails meeting the definition of Federal Records.	7. No documentation or response received other than the limited information in the e-mails provided for Request 1 above.

Different MACT Floor Proposals

Source	Emission Limits (Input base - lbs/Tbtu)													
	Process Sub-Categories								Coal Type Sub-Categories					
	FBC	FBC (sub-Bit. + Bit)	FBC - Lignite	Other	Bit. - Hot	Bit. - Wet	Bit. - Saturated	IGCC	Sub-Bit. + Bit.	Bit.	Sub-Bit.	Lignite	Coal Refuse	Total Estimated Emissions
EPA Proposed Rule	NA	NA	NA	NA	NA	NA	NA	19.0	NA	2.000	5.800	9.200	0.4	34 [1]
FACA-Environmental	0.190	NA	NA	0.210 [2]	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.9 [3]
FACA - Industry	2.000	NA	NA	NA	3.700	3.200	2.200	NA	NA	NA	4.200	6,500	NA	25-30 [3] 36 [6]
FACA - State & Local - Option 1	NA	NA	NA	NA	NA	NA	NA	NA	0.600	NA	NA	NA	NA	6.7 [3]
FACA - State & Local - Option 2	NA	NA	NA	NA	NA	NA	NA	NA	0.400	NA	NA	NA	NA	6.3 [3]
FACA - Clean Energy Group	NA	0.320	12.0	NA	NA	NA	NA	NA	1.223	NA	NA	9.091	NA	13.1 [3]
Clean Air Task Force [4]	NA	NA	NA	NA	NA	NA	NA	4.9	NA	0.420	1.500	4.500	0.1	12 [5]

Abbreviations

Bit.: Bituminous
FACA: Federal Advisory Committee Act
FBC: Fluidized Bed Combustion
lb/Tbtu: pounds per Trillion British thermal units
IGCC: Integrated Gasification Combined Cycle
MACT: Maximum Achievable Control Technology
NA: Not Applicable

Notes:

1 Estimate based on Integrated Planning Model results.
2 Applied to all units except FBC
3 Based on estimates developed by Northeast States for Coordinated Air Use Management.
4 Clean Air Task Force preferred a MACT with no sub-categorization but re-computed a MACT floor based on EPA's proposed subcategories.
5 Based on Integrated Planning Model run and includes co-benefit reductions from Clean Air Interstate Rule.
6 Based on calculations performed by the industry group.

EPA's Rule Development Process

EPA actions are assigned to one of three tiers based on the nature of the anticipated issues and the level of cross-Agency interactions needed to ensure a quality action. The proposed rule is a Tier one rule and meets the following criteria.

Tier 1 Criteria: Administrator's Priority Actions
This tier will include top actions that demand the ongoing involvement of the Administrator's office and extensive cross-Agency involvement on the part of the Assistant/Regional Administrators.

Factors to consider in making a judgment about placing an action in Tier 1 are:

- major cross Agency or cross-media policy implications or precedents
- potential for major or precedent-setting implementation issues
- potential for major cross-Agency, cross-media, or inter-agency controversy
- potential for major economic impact on other levels of government or the regulated community
- highly controversial in terms of external interest
- ongoing, formal involvement of the Agency's highest level of management (Administrator, Deputy Administrator) is necessary or desired
- presents a significant opportunity for the Agency to advance the Administrator's priorities

Action should be placed in Tier 1 if...

- science issue(s) are precedent setting and controversial
- economically significant per Executive Order 12866 (i.e., > $100 million), unless the program office can justify placement in Tier 2
- economics issue(s) are precedent setting and controversial

The program office develops the proposed rule, which may take months to years depending on the complexity of the rule, priorities, and court/statutory deadlines. Rule development follows five major stages, as outlined in the Agency's Action Development Plan. The first stage is determining the proper tier for the action based on the criteria outlined above. The following table describes the five stages of an Action Development Plan.

Five Major Stages of an Action Development Plan

Stage 1. Tiering the Action

- Understand tiering
- Place action in the appropriate tier
- Obtain tiering approval

Stage 2. Developing the Proposed Rule or Draft Action

- Charter the workgroup
- Get the workgroup underway
- Prepare the preliminary analytic blueprint and get early guidance from senior management
- Prepare the detailed analytic blueprint
- Senior management approval of analytic blueprint
- Complete data gathering, consultation, peer review, analyses, and options development
- Select Options
- Develop the proposed action by preparing preamble, rule, and supporting documents
- Conduct Final Agency Review to ensure senior management approval
- Office of Policy, Economics, and Innovation review for rules deemed as "significant" under Executive Order 12866

Stage 3. Requesting OMB Review for Proposed and Final Actions (if necessary)

- Determine if OMB review is necessary. Only those regulatory actions designated "significant" under Executive Order 12866, "Regulatory Planning and Review" are subject to review by OMB (e.g., actions having an annual effect on the economy of $100 million)
- Prepare regulatory action for submission to OMB
- Address OMB's comments
- Docket the OMB review process

Stage 4. Requesting the Administrator's Signature and Publishing an Action

- Request the Administrator's signature
- Publish the action in the Federal Register and open docket(s)

Stage 5. Developing the Final Action and Ensuring Congressional Review

- Receive public comments
- Consider and address public comments
- Determine next steps
- Submit actions to Congress under the Congressional Review Act or the Courtesy Copy Policy

Agency Comments to the Draft Report and OIG Evaluation

MEMORANDUM

SUBJECT: Comments on the December 17, 2004 Draft Evaluation Report Entitled, Additional Analyses of Mercury Emissions Needed Before EPA Finalizes Rules for Coal-Fired Electric Utilities

FROM: Jeffrey R. Holmstead
Assistant Administrator for Air and Radiation
U.S. Environmental Protection Agency

William H. Farland, PhD
Acting Deputy Assistant Administrator for Science
Office of Research and Development
U.S. Environmental Protection Agency

TO: Nikki Tinsley
Inspector General
U.S. Environmental Protection Agency

DATE: January 24, 2005

Thank you for giving us the opportunity to review the draft report referenced above and to open dialogue with OIG staff. We have substantial concerns with the referenced draft including several inaccuracies and flaws that we feel must be addressed before the report is finalized. This memorandum briefly summarizes our major concerns.

Agency scientists and experts know a great deal about mercury: what are the sources, both domestically and internationally; where does mercury in this country come from; what is the chemistry that converts mercury deposited on the land and in the water into mercury that becomes available to the food chain; what are the routes of exposure in this country to mercury; what are the potential impacts of controls on that exposure; and what is the status of the various technologies now being studied.

While some questions remain in our understanding of many of these linkages, this will not prevent the Agency from regulating mercury from power plants, and it will do so as effectively as possible, informed by the full body of knowledge it now possesses. The Agency also recognizes that mercury emissions from facilities as complex as coal-fired power plants should not be considered in isolation of the other efforts to reduce air pollution; hence the Administration's strategy to further control SO_2 and NOx while instituting new, specific regulations for mercury. The Agency believes that such a

a strategy can deliver significant overall health benefits to a broad segment of the American public.

EPA strongly urges the IG to take the broad base of information we know about mercury, as well as the outstanding unanswered questions, into consideration when developing the final report.

1. **The draft report criticizes the rulemaking process as being incomplete even before a final rule is issued.** This critique rings hollow given the iterative nature of rulemaking. The rulemaking process consists of a proposed rule, a public comment period and often additional information before final decisions are made. The IG characterized the process as incomplete before the process had finished. For example, a number of the issues regarding benefit-cost analysis raised in the draft report are issues that the Agency is working on as evidenced by its Notice of Data Availability on November 30, 2004.

> ***OIG Response:*** *Our review was initiated at the request of seven U.S. Senators, who asked that we complete this review in sufficient time to allow the Agency to address any issues raised in our report. We have added information to the Scope and Methodology section in Chapter 1 of the Final Report explaining that our review was completed while the Agency was still in the process of finalizing the rule. Accordingly, our report reflects findings and observations about the status of the process at the time we completed our review. We look forward to seeing the results of the Agency's additional cost-benefit analyses, as recommended in our report.*

2. **The draft report inaccurately suggests that US power plant mercury emissions represent a large part of the human exposure problem.** Most exposure to mercury comes from eating fish from the world's oceans and the mercury in these fish comes from a variety of sources released over many years, including natural emissions like volcanoes, and anthropogenic emissions from many countries, representing emissions from a variety of sectors, in addition to emissions from US power plants. It is because US power plants are part of the larger problem that EPA has proposed, for the first time ever, to require reductions from this sector.

Given the global nature of mercury exposure and the uncertainty in the time to realize benefits from current emission reductions, the action to reduce mercury emissions from power plants must be seen in the larger context of all the activities EPA and others in the international community are implementing to reduce exposure to mercury.

OIG Response: *Our draft report did not suggest that mercury emissions from U.S. power plants represent a large part of the human exposure problem. Power plants are one of many sources of mercury emissions. The primary objective of our review was to assess EPA's development of the proposed rule for regulating mercury emissions from coal-fired electric utility units, and we included information in our draft report on mercury emissions and mercury health effects for background purposes. Nonetheless, we have included additional information in Chapter 1 of the Final Report to put total U.S. mercury and U.S. power plant emissions in the context of global mercury emissions. We understand that primary route of human exposure to mercury is through the consumption of fish and that the Centers for Disease Control and Prevention surveys indicate that seafood is the predominant type of fish consumed by women of child-bearing age and children. However, certain subgroups, such as Native Americans, eat more fresh-water fish and may be more susceptible to mercury exposure than others. We added this information to the background section of our final report.*

3. **The draft report does not comprehensively and accurately describe how the proposed cap-and-trade system would work, leading the reader with misimpression about what our experience and modeling has taught us.** The draft report fails to recognize that a cap-and-trade system requires emissions reductions on a concrete timeline of declining caps, thus leading to continual reduction of emissions and promotion of new technologies. It also fails to acknowledge that, under this system, the largest emitters typically will be the first to reduce their mercury emissions and will generally achieve the greatest level of reductions.

The draft report criticizes the cap-and-trade proposal for not requiring the installation of mercury-specific controls until 2018, but this is inaccurate and reflects a misunderstanding about how cap-and-trade works. The report should recognize the fact that it is reductions in mercury emissions that will lead to improvements in public health and these reductions will occur much earlier than 2018. Moreover, neither the Maximum Achievable Control Technology (MACT) approach nor the cap-and-trade approach would require any particular technology for controlling mercury. Either approach would require power plants to meet certain standards for mercury control, and then let individual plants find the best way to meet those standards.

OIG Response: *One of the objectives of our review was to evaluate whether the proposed mercury cap-and-trade rule was sufficiently protective of public health. As a result, we highlighted certain concerns with the rule as proposed. As such, we limited our focus of the mercury cap-and-trade proposal to concerns about the interim cap level, the potential for hot spots formation, the safety valve provision, the exemption of small emitters, and tribal impacts.*

Our draft report portrayed an accurate representation of how the mercury cap-and-trade program works. While the proposed mercury cap-and-trade rule should ultimately result in emissions reductions, we do not agree that the proposal provides a "concrete timeline of declining caps." For example, the proposed rule provides an interim cap that is based on co-benefits from existing technologies and can be achieved without the implementation of mercury-specific controls. Since the interim cap for mercury emissions can be achieved without mercury-specific controls, the proposed rule may not adequately promote the use of new technologies. Also, the only other mercury cap is the 2018 final cap, and EPA modeling indicates it may not be met in 2018 due to the banking provisions of the proposed mercury trading program. Finally, our draft report noted that neither the proposed cap-and-trade nor the MACT option require the use of any specific technology.

While EPA has experience with cap-and-trade programs such as the Acid Rain program, there are differences in the transport and fate of SO2 and mercury emissions which need to be addressed in a cap-and-trade approach to controlling mercury emissions. For example, SO_2 emissions are primarily deposited regionally and globally, while mercury can deposit locally. Additional differences between these two cap-and-trade programs were highlighted in Chapter 3 of the draft report.

4. The draft report incorrectly characterizes the calculation of the MACT standard. The draft report did not independently calculate the MACT floor, but instead simply relied on assertions made by critics of the proposal as the basis for their critique. The proposed MACT floor was calculated in accordance with the requirements of CAA Section 112(d) by basing the standard on what the top performing 12 percent of units were achieving in practice, taking into account subcategorization and variability..

Contrary to the claims in the draft report, the Agency did investigate beyond-the-floor MACT alternatives and did propose a beyond-the-floor standard where technology was found to be available (i.e., Integrated Gasification Combined Cycle (IGCC) subcategory).

OIG Response: The OIG did not inaccurately characterize the calculation of the MACT floor. Our analysis was based on discussion with a number of EPA stakeholders and EPA officials, and review of supporting documentation. We found evidence that although the MACT floor was ostensibly based on data from the top performing 12 percent of units, this data was analyzed with a final target already in mind, i.e., 34 tons. As stated in the Agency's Comment 5 to our draft report, this "floor" of 34 tons was obtained during the Clear Skies legislative process. Accordingly, we do not consider this floor to be based on an unbiased analysis of what the top performing 12 percent of units were achieving.

With respect to IGCC units, our review focused primarily on the development of the standards for existing units. Of the over 400 coal-fired power plants in operation in the U.S., two are IGCC plants. Although EPA did not propose a beyond-the-floor standard for existing IGCC units, EPA proposed an emission limit for new IGCC units that was below the calculated floor for IGCC units and was based on EPA's determination that mercury reduction of 90 percent could be obtained for this subcategory through the use of carbon bed technology.

5. The draft report suggests that the proposed rule was flawed because other regulatory alternatives that would achieve emissions levels lower than about 34 tons per year were not developed or proposed. In particular, the draft report makes much of the fact that the MACT proposal was developed with the goal of achieving a nationwide emissions level from affected power plants of about 34 tons per year. The report fails to consider the fact that EPA had developed extensive information about mercury emissions and control techniques in the power sector during the MACT regulatory development process and during the development of the Clear Skies initiative. That work caused us to conclude that mercury reductions could, in fact, be achieved in the power sector over the 3-4 year MACT compliance period specified by the statute. However, these reductions would not come for the most part from mercury-specific controls (such as activated carbon injection). Extensive work conducted by the Office of Air and Radiation and the Office of Research and Development indicated that mercury-specific controls will not become readily available for commercial application to this industry until 2010 or later - well beyond the MACT compliance period. Consequently, the proposed rule is predicated on the assumption that virtually all mercury reductions during the MACT compliance period would have to be accomplished as a co-benefit of installing air pollution controls designed to remove SO_2 or NOx. As part of the Clear Skies effort, EPA had extensively studied the capacity of the power sector to install SO_2 and NOx controls during the period up to 2010. That work showed that 34 tons per year was the lowest level of mercury emissions that we could reasonably expect the power sector to achieve through the aggressive application of SO_2 and NOx controls up to 2010. Further, as a part of the FACA process established for this rulemaking, industry submitted what they thought would be possible under a true co-benefit approach (i.e., no mercury-specific controls). Their estimate was that 36 tons per year of mercury would be emitted under a MACT approach. The EPA proposal is grounded in careful analysis as to what levels of mercury control reasonably can be expected over the MACT compliance period.

OIG Response: *Our draft report concluded that the MACT development process was compromised for several reasons. This included the fact that several MACT floor proposals were lower than the EPA's proposed MACT rule, including several proposals developed by EPA in trying to achieve a floor that would result in annual emissions of 34 tons. This included two EPA IPM runs that showed national emissions of 29 tons and 27 tons, that were not included in the rulemaking docket or available for public comment. While the Agency has conducted analysis to determine the co-benefit of SO_2 and NOx controls, we do not believe this meets the requirements of CAA section 112(d) in developing the MACT standard. For example, the co-benefit is based on an average performance of all units, not just the best performers. We continue to believe the Agency should conduct additional analyses before finalizing the rule. As noted in the draft report, the Government Accountability Office is conducting a review of technology-related issues for the proposed mercury rule.*

6. The draft report fails to recognize the nature of the regulatory development process and incorrectly states that EPA "did not adequately evaluate the environmental health effects of the proposed rule on children." We have made it clear from the start of the rulemaking process that the health effects of greatest concern are possible developmental effects in fetuses and young children exposed to unsafe levels of methylmercury. Unlike most other rules that EPA develops, this rulemaking is singularly directed at developing an appropriate regulatory approach for addressing the potential impacts on children. Evidence of this can be seen in EPA's first guiding principle in the development of a final mercury rule which states that the rule will concentrate on the need to protect children and pregnant women from the health impacts of mercury.

Consistent with this principle, EPA Office of Air and Radiation participated in an ongoing dialogue with the Children's Health Protection Advisory Committee (CHPAC) and responded to CHPAC's recommendations on mercury exposure in children. Further, EPA and others have conducted extensive work on the health effects of mercury for the developing fetus and young children, including a National Academy of Sciences review completed in 2000. The Inspector General's draft report misses this key point.

OIG Response: *We do not believe we failed to recognize the nature of the rulemaking process. Further, the Agency should have more comprehensively evaluated the proposed cap-and-trade rule's impact on children's health. A cap-and-trade program, while reducing overall emissions, can result in geographically uneven distributions of emissions. The proposed rule did not include an analysis of where or how likely such varying mercury emissions and resulting depositions could occur, and what impact this may have on children's health.*

Children's Health Protection Advisory Committee members did not characterize their interaction with the Agency as an ongoing dialogue. Committee members told us that the Agency's response to their concerns with the proposed rule did not satisfactorily address their recommendations.

7. The draft report improperly characterizes the process by suggesting that it has not been sufficiently inclusive. EPA has held dozens of high-level inter-office and external meetings on this rule. This inclusive process was needed both because the rule has far-reaching national implications for human health, the environment, and the economy and also because a well-informed decision on an issue this complicated requires hearing diverse perspectives. While there is always room to improve communications within and with those outside of EPA, there is little basis to fault the Agency in this case.

OIG Response: *The OIG does not agree that the Agency review process was inclusive. As we noted in our draft report, according to staff involved, the intra-agency work group review process followed in this rulemaking varied significantly from past Agency practice and applicable guidance for Tier One rules. Specifically, the work group process followed in this rulemaking was unusual in its short duration, infrequent meetings, late start with respect to the final rule deadline, and overall lack of communication and feedback between the work group and Agency decision makers. Further, work group members were not given the opportunity to review and comment on an entire draft proposal before it was published in the Federal Register. For example, staff from the Office of Enforcement and Compliance Assurance were never given a draft of the proposed rule to review or comment on, thus this office could not assess the adequacy of the proposed rule's monitoring, record keeping, or reporting provisions as it typically does for Tier One MACTs. With respect to meeting with external stakeholders, tribal representatives told us that they were not consulted during the development of the proposed cap-and-trade option. Given this rule's far-reaching national implications for human health, the environment, and the economy, the OIG believes it was important for the Agency to have been more inclusive of available Agency expertise and external stakeholder input in developing this proposed rule.*

Again, thank you for the opportunity to review the draft report. We would be happy to work with you and your staff to ensure that you promptly receive all the information and analysis you need to finalize the report. The final report should include an improved discussion of (1) the global nature of mercury exposure and the uncertainty in the time to realize benefits from current emission reductions; (2) how a proposed cap-and-trade system would require emissions reductions on a concrete timeline; (3) the approaches to calculation of the MACT floor; (4) the substantial effort EPA devoted to evaluating the risk of mercury exposure on children; and (5) the inclusiveness of EPA's process towards reaching a final rule.

OIG Response: *The Agency's comments have been included in the final report as appropriate. We appreciate the efforts of both the Office of Air and Radiation and the Office of Research and Development in working with us to clarify certain technical issues and in providing prompt input so that we could issue our report in a timely manner.*

Appendix F

Distribution

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Inspector General (2410)

Appendix I:
2004 Everglades Consolidated Report, Chapter 2B: Mercury Monitoring, Research and Environmental Assessment

Chapter 2B: Mercury Monitoring, Research and Environmental Assessment

Tom Atkeson and Don Axelrad

SUMMARY

Mercury remains one of the major water quality concerns for the Everglades restoration program. Efforts by the South Florida Water Management District (SFWMD or District) and the Florida Department of Environmental Protection (FDEP) in leading the South Florida Mercury Science Program (SFMSP)[1] continue to improve the understanding of the sources, transformations, toxicity, and fate of mercury in the Everglades. The SFMSP seeks to provide scientific information on environmental cycling of mercury at local, regional, and global levels to better support decision making in South Florida. General information on the nature of the environmental mercury cycle has been presented in previous Everglades Consolidated Reports. This chapter serves to update the findings previously reported, with supporting data and other technical information on mercury being provided in the appendices to this chapter[2].

The updated findings from this collaborative effort on mercury include the following:

- Although the precise proportions of locally-derived versus global mercury remain uncertain, the data indicates that a significant proportion of mercury deposition to the Everglades originates from sources within southern Florida. Newly deposited mercury is converted to methylmercury over a period of hours to days.
- Methylmercury, a highly toxic form of mercury, is primarily produced in sediments by naturally occurring, sulfate-reducing bacteria. Methylmercury strongly

[1] This partnership of federal, state, and local interests includes the FDEP, the District, the U.S. Environmental Protection Agency Office of Research and Development and Region 4, the Florida Fish and Wildlife Conservation Commission, and the U.S. Geological Survey. Other collaborators associated with the SFMSP are the U.S. Fish and Wildlife Service, the U.S. Park Service, the U.S. Army Corps of Engineers, the University of Florida, Florida State University, Florida International University, the University of Miami, the University of Michigan, Texas A & M University, Oak Ridge National Laboratory, the Academy of Natural Sciences of Philadelphia, Florida Power and Light, Florida Electric Power Coordinating Group, the Wisconsin Department of Natural Resources, the Electric Power Research Institute, and the National Oceanic and Atmospheric Administration.

[2] Appendices 2B-1 through 2B-7 of the *2004 Everglades Consolidated Report* provide additional detail to meet the Everglades Forever Act (EFA) requirement that the District and the FDEP shall annually issue a peer-reviewed report regarding the mercury research and monitoring program that summarizes all data and findings. Appendix 2B-5 of this report meets the reporting requirements of the EFA, as well as specific permits issued by the FDEP to the District. Readers who desire additional, detailed scientific information should consult the specific chapters on mercury monitoring and assessment presented in the *1999 Everglades Interim Report* and previous Everglades Consolidated Reports.

bioaccumulates in the aquatic food chain, and its production is highly influenced by the rate of supply of atmospherically derived mercury and by sulfate concentrations.

- Methylmercury production and bioaccumulation are influenced by many factors associated with water quality, including sulfate, sulfide, nutrients, temperature, and light levels.
- The central and southern Everglades exhibit strong methylmercury production and bioaccumulation and, therefore, high mercury levels are found in fish and wildlife. At the apparent peak of mercury in Everglades biota in the mid 1990s, these levels were high enough to pose a risk of chronic toxicity to wildlife. Subsequent declines in body burdens have eased this concern, but mercury risk to humans and wildlife continues to be a water quality concern.
- The primary emissions sources of mercury in southern Florida circa 1990 were incineration (both municipal solid waste and medical waste) and power generation. Mercury emissions from incinerators of all types have declined by approximately 99 percent since the late 1980s. Principal reasons for this decline were pollution prevention activities and emissions controls that resulted in reductions of mercury wastes.
- Monitoring of Everglades fish and wading birds indicates a significant decline in mercury over the period from 1994 to 2003 in both largemouth bass and great egrets by at least 60 percent. Largemouth bass from Central Florida lakes have declined by approximately 40 percent. Largemouth bass mercury levels have not declined in the Everglades National Park, for reasons that remain obscure.
- Mercury levels in largemouth bass, despite substantial declines in recent years, remain well above the proposed 0.3 milligrams per kilogram (mg/kg) fish tissue criterion proposed by the U.S. Environmental Protection Agency.
- Environmental mercury models for the Everglades have been developed and incorporate the latest findings from atmospheric and aquatic research. Results substantiate a strong relationship between atmospheric mercury load to the Everglades and mercury levels in top predator fish.
- Aquatic system modeling analyses indicate that the response times of the Everglades to changes in atmospheric load are short. Modeling analyses suggest that significant benefits can be expected within a decade of sustained load reductions, with the ultimate benefits occurring within about 30 years. Monitoring data suggests that the Everglades has responded to decreased mercury emissions from South Florida. Trend monitoring confirms these reductions, which appear to take effect more rapidly than model predictions.

The monitoring, research, modeling, and assessment studies described in this chapter and its appendices were coordinated among the collaborators in the SFMSP. This group of agencies, academic and private research institutions, and the electric power industry has advanced the understanding of the Everglades mercury problem more effectively and faster than what could have been accomplished individually by either the FDEP or the District. The SFMSP has operated under a coordinated plan; however, each agency operates within its own management and budgeting framework. The goal of the SFMSP is to provide the FDEP and the District with information to help the two agencies make mercury-related decisions about the Everglades Construction Project, as well as other restoration efforts, on the schedule required by the

Everglades Forever Act. Consequently, SFMSP studies are now providing a better understanding of why the Everglades is an "at-risk" system for mercury contamination.

GLOSSARY OF MERCURY-RELATED ACRONYMS AND TERMS

The general glossary in the *2004 Everglades Consolidated Report* includes terminology from all the report's chapters. However, because mercury is a complex environmental contaminant, the following mercury-specific glossary is provided to further assist readers in understanding the material presented in Chapter 2B of this report.

- **ACME Project:** The Aquatic Cycling of Mercury in the Everglades Project. A process-oriented mercury research program organized by the U.S. Geological Survey.
- **E-MCM:** Everglades Mercury Cycling Model. A computer model of mercury cycling. The model is being refined under the auspices of South Florida Water Management District, the Florida Department of Environmental Protection, and the U.S. Environmental Protection Agency to predict changes for mercury in the Everglades in response to changing loads or water quality.
- **EPA:** Everglades Protection Area. The EPA is comprised of Water Conservation Areas 1, 2A, 2B, 3A, and 3B, the Arthur R. Marshall Loxahatchee National Wildlife Refuge, and the Everglades National Park.
- **FAMS:** Florida Atmospheric Mercury Study. An early study to quantify deposition of mercury from the atmosphere to the Everglades and other parts of Florida.
- **Hg:** The standard chemical abbreviation for the element mercury.
- **MeHg:** The standard chemical abbreviation for the compound methylmercury. A particularly toxic organic form of mercury that concentrates in aquatic food webs.
- **REMAP:** Regional Environmental Monitoring and Assessment Program. The U.S. Environmental Protection Agency Region 4 and Office of Research and Development have used the REMAP approach to conduct an Everglades-wide ecosystem assessment for mercury and water quality.
- **RGM:** Reactive gaseous mercury. A form of gaseous mercury in the atmosphere that is readily deposited by rainfall and dry deposition.
- **SFMSP:** South Florida Mercury Science Program. A state-federal-private partnership established to determine the causes and possible solutions to the mercury problem in Florida.
- **STA:** Stormwater Treatment Area. A constructed wetland designed to remove phosphorus from inflowing waters prior to discharge into the Everglades.
- **SRB:** Sulfate-reducing bacteria. Microbes, commonly found in sediments, which transform inorganic mercury into methylmercury.
- **TMDL:** Total maximum daily load. Pollutant load determinations for a water body not meeting its designated use as required under the federal Clean Water Act.

RESEARCH PROGRESS

The following research needs were identified in previous Everglades Consolidated Reports (ECRs) from the South Florida Water Management District (SFWMD or District). An update on the progress made with respect to each of the research needs is presented below.

1. Quantify the wading bird diet-egg relationship to support a revised numerical Class III water quality standard for total mercury, based on methylmercury levels (2000 ECR). Local source: Ecological Risks of Mercury (2001 ECR).

   The U.S. Geological Survey Biological Resources Division's (USGS-BRD) Patuxent Wildlife Research Center initiated a study of the *in-ovo* effects of methylmercury. Dr. Gary Heinz, principal author of the much-cited study of the multigenerational effects of mercury on domestic mallard ducks, has subsequently obtained extensive collections of fertile eggs from several wading bird species and has conducted detailed studies of egg viability and hatchability.

   Heinz (2002) found that the embryos of various species of birds differ in their sensitivity to methylmercury. His results indicate that the former, presumably protective, "reference dose" for estimating mercury risk to fish-eating birds was, in fact, not protective. The presumption had been that domesticated ducks used in earlier studies were the most sensitive species, as these largely herbivorous birds have low exposure to methylmercury. However, subsequent study involving several species of fish-eating birds, including species found in the Everglades such as white ibis *(Eudocimus albus)*, great egret *(Casmerodius albus)*, and tricolored heron *(Egretta tricolor)*, indicated that these species were as much as seven times more sensitive to methylmercury toxicity.

   The Florida Department of Environmental Protection (FDEP), with potential support from the USGS-BRD and the U.S. Fish and Wildlife Service (USFWS), plans to complement the laboratory studies being done at Patuxent Wildlife Research Center with a multigenerational feeding study of mercury effects on fish-eating birds. A captive colony of white ibis will be established in Gainesville, FL for controlled experimental studies. It is planned that the aviary will be constructed in time for the 2004 spring breeding season and that the studies will continue for four years.

2. Quantify "global versus local" and "new versus old" sources of mercury (2001 ECR). Local source: Receptor Relationships of Mercury (2002 ECR).

   The FDEP and the U.S. Environmental Protection Agency (USEPA) continue to support atmospheric mercury studies relevant to the mercury control policy in U.S. southeast coastal regions, sponsor studies that directly measure transport of mercury species into Florida, describe and quantify the atmospheric reactions of mercury that facilitate deposition, and employ photochemical grid models to organize the atmospheric processes research into decision making. The operation of two sites in the Speciated Atmospheric Mercury Study (SAMS) project by the Broward County Air Quality Division is continuing. This project focuses on the paramount importance of the speciation of mercury in the atmosphere in controlling the transport and fate of mercury. SAMS makes highly time-resolved measurements of all known forms of atmospheric mercury and associated tracer species. It is expected that this measurement and modeling project will continue through 2003 and will provide improved data, tools, and understanding in the effort to resolve the question of the importance of long-distance transport of mercury into Florida.

Earlier analytical bottlenecks at the USEPA Office of Research and Development (ORD) National Exposure Research Laboratory's x-ray fluorescence laboratory have been resolved, and the substantial backlog of elemental tracer samples has been analyzed. Several reports and publications relating to the measurement and modeling of mercury deposition have been completed or are currently in press (e.g., Malcolm et al., 2003; Marsik, in prep.).

Results from the Pompano Beach site during the Florida Everglades Dry Deposition Study (FEDDS) in summer 2000 indicated that reactive gaseous mercury (RGM) concentrations below onshore wind flow regimes were quite low (typically less than 10 picograms per cubic meter (pg/m^3]), contributing a negligible input of mercury over southern peninsular Florida. Other measurement and meteorological data will be useful in the further modeling of long-distance transport phenomena that potentially influence Florida.

3. Revise the Everglades Mercury Cycling Model (E-MCM) to include food web uptake dynamics and relationships between phosphorus and sulfur concentrations and mercury dynamics (2001 ECR).

Research aimed at defining both the details of the mercury methylation process and its quantitative relationships with factors that influence this process is important to learning what it is that controls the effective net production of methylmercury in the aquatic system. The SFMSP has devoted significant effort to this topic from 2001 through 2003. A specific focus has been to organize the work around the requirements of the E-MCM while incorporating qualitative and quantitative information as it becomes available into the evolving E-MCM to make it a more robust tool for evaluating management options. The data and insight from field studies are being fed directly into model formulation and testing. The results are then used to calibrate and test the E-MCM in order to simulate the effects of various hydrology, water quality, or restoration activities.

The E-MCM development and application is detailed in Appendix 2B-2. It remains an SFMSP goal to continue to develop the E-MCM as a tool to assess systemwide responses to mercury sources, water quality, and management scenarios being evaluated by the Comprehensive Everglades Restoration Plan (CERP).

4. Geochemical controls on mercury methylation (2001 ECR).

The FDEP continues to support a series of studies with the USGS and the Academy of Natural Sciences of Philadelphia, Estuarine Research Laboratory. Field mesocosm experiments using stable-isotope and other tracer techniques have been used to examine the interactions between mercury, sulfur, nutrients, dissolved organic carbon, and other water quality variables. The results of these mesocosm studies are presented in Appendix 2B-3. Fieldwork began with deployment of mesocosms in spring 2001; field experiments are presently scheduled through June 2005. The further influence of the effects of wetting and drying cycles on methylmercury production is presented in Appendix 2B-1.

5. Trends of mercury in Florida (2002 ECR).

One of the most illuminating uses of monitoring data has been evaluating mercury trends over time. For example, the sediment coring studies of the early 1990s by Rood et al. (1995) revealed that mercury accumulation in Everglades soils was more than five times greater than in 1900, confirming the viewpoint that anthropogenic influences have dominated mercury cycling. However, following that study is a hiatus of 10 critical years in the record to describe the direction and magnitude of mercury impinging on South Florida. To close this data gap,

the FDEP is sponsoring a revisit of that work by selecting several water bodies (e.g., lakes and borrow pits) with sedimentary profiles more ideal than those in the Everglades. The prime contractor is the Science Museum of Minnesota, with assistance from the University of Florida, the University of Connecticut, and Tetra Tech, Inc.

Additional fieldwork for sediment coring studies was completed in 2002. However, some cores could not be analyzed from the three water bodies that were initially sampled (Gator Lake, 9-Mile Pond, and West Lake) due to problems encountered with these cores. During a follow-up field trip in 2003, multiple cores also were collected from three lakes in South Florida (Lake Annie, Gator Lake, and Gary Lake [old borrow pits]). Preliminary analyses of the cores indicate that sediment profiles for these lakes are suitable, and the lead-210 dating is currently underway. Project completion is currently on schedule for November 2003. This project should yield high-resolution information on the trend of mercury accumulation (i.e., mercury deposition) in South Florida. It is anticipated that this data, in conjunction with other trend information developed by the FDEP and its collaborators, will allow evaluation of the outcomes and effectiveness of controls on mercury use and emissions. It is expected that this work will be reported in the *2005 Everglades Consolidated Report*.

Analyses of long-term trends of mercury in Everglades wading birds are presented in Appendix 2B-4. Information obtained recently on the relationship between the stability of methylmercury in animal hair and feathers and the potential confounding effects of inorganic mercury formerly used as preservatives in museums has been used by researchers from the University of Florida to construct a historical record of mercury in biota from South Florida. This reconstruction indicates an increasing trend from the late 1800s to approximately 1990. Direct measurements of mercury in animal hair and feathers collected by the District and the FDEP show a decline that began in the mid 1990s.

THE MULTIMEDIA CYCLE OF MERCURY

The accumulation of mercury in fish is one of the water quality problems in the Everglades being addressed by the South Florida Water Management District and the Florida Department of Environmental Protection in their activities under the Everglades Forever Act and the Comprehensive Everglades Restoration Plan. This problem first became apparent in 1989, when the Florida Department of Health issued mercury-related health advisories to fishermen. These recommendations, the first ever in Florida, urged fishermen not to eat largemouth bass (a popular sport fish) from most of the Everglades and to consume only limited amounts of several other species of sport fish because of a risk of mercury toxicity to consumers. The high levels of mercury found in fish also pose a risk of toxicity to fish-eating wildlife.

The mercury problem in the Everglades, as in many other waters, is a multimedia problem, meaning that more than one aspect of the environment is involved. To understand the individual components of the problem, the disciplines of air quality, water quality, and ecological risk must be combined to encompass the disparate facets of the mercury problem. A conceptual model of the mercury problem is presented in **Figure 2B-1**.

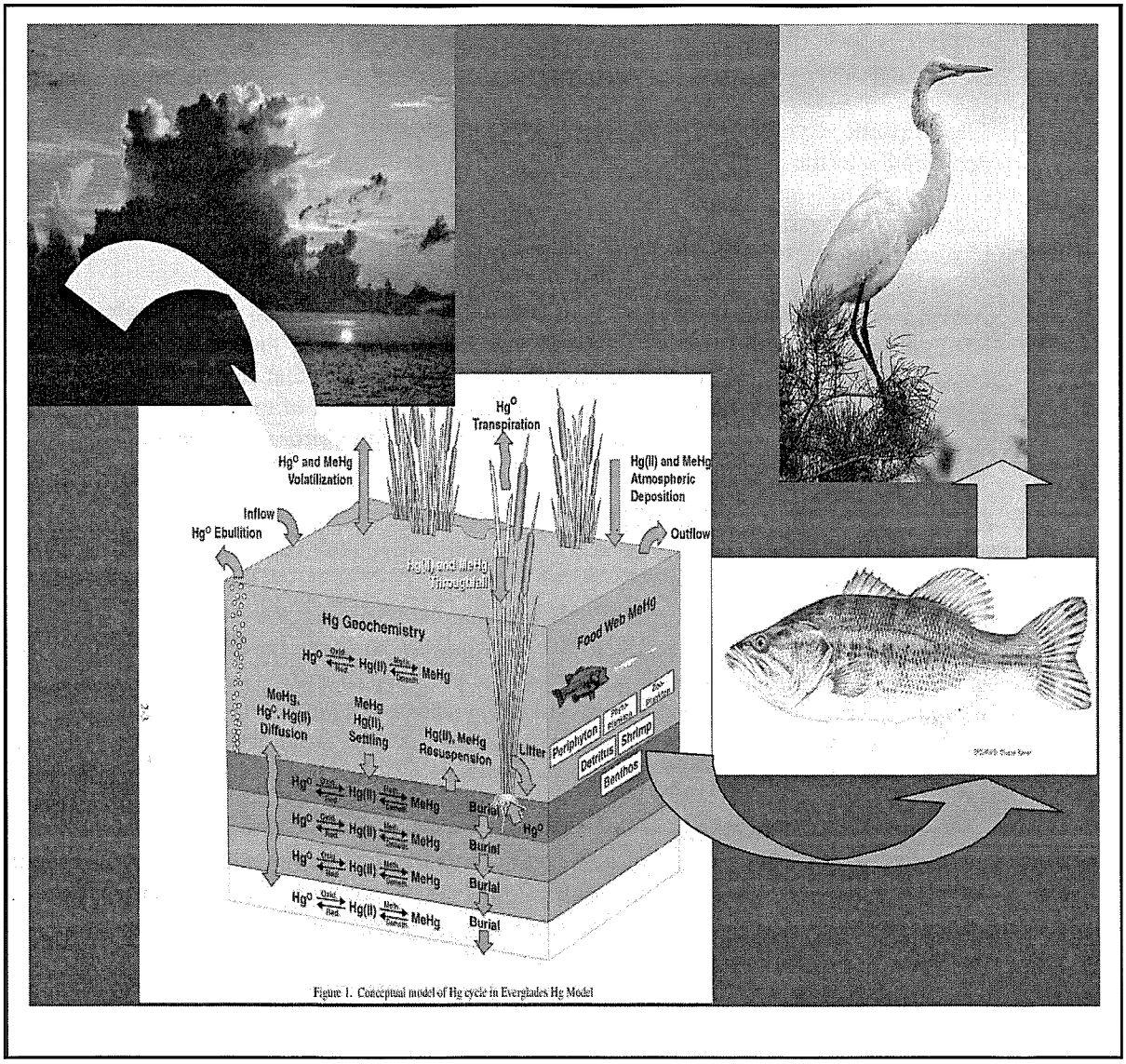

Figure 2B-1. Illustration of the multimedia cycle of mercury for atmospheric transport and fate, aquatic biogeochemical cycling, bioaccumulation, and ecological risk.

The most important concepts to keep in mind regarding the environmental mercury cycle are as follows:

- **The Atmospheric Mercury Cycle.** Human mining, industrial activities, air pollution, and deposition since the Industrial Revolution have increased, by about fivefold, the amount of mercury (Hg) that naturally cycles through the atmosphere. Mercury pollution in the air comes from the mining and smelting of mineral ores (which contain small amounts of mercury), the burning of fossil fuels (e.g., coal and oil), the use and disposal of mercury, and the incineration of waste, principally municipal and medical wastes. The predominant source of mercury to the Everglades is atmospheric deposition. Mercury deposited from the atmosphere is approximately 95 to 98 percent of the total mercury

input to the Everglades Protection Area (EPA) (the 1994 and 1995 mean is approximately 220 kilograms per year [kg/yr]); mercury input from discharges of surface water to the EPA is relatively minor (the 1994 and 1995 mean is approximately 3 kg/yr). Dry deposition of gaseous and fine particulate mercury is about one-third of rainfall deposition.

- **The Aquatic Cycle of Mercury – Biotransformation and Bioaccumulation.** Once deposited into the Everglades, mercury is quickly distributed through the shallow water column and into sediments, where a fraction of the mercury is transformed by naturally occurring bacteria to methylmercury (MeHg). Methylmercury is very toxic and bioaccumulates efficiently from the water up through aquatic food webs.

- **Assessment of Methylmercury Risk to Everglades Wildlife – Ecological Risk.** Methylmercury in top predator fish (e.g., largemouth bass) in the Everglades has been measured to be as much as ten-millionfold higher than that of the surface water associated with these fish. This phenomenal bioaccumulation of mercury results in a risk of mercury toxicity to humans and wildlife, such as wading birds, that feed on fish.

THE ATMOSPHERIC MERCURY CYCLE – AIR POLLUTION AND DEPOSITION

When mercury was first discovered to be in Everglades fish in the late 1980s, little was known about the causes of the mercury problem. Answers to even the most basic questions regarding mercury were unknown, such as whether the presence of mercury was simply a natural condition in the Everglades, whether the area had always been that way, what were the sources of mercury, what levels were safe or harmful, and, most importantly, what could be done to reduce or alleviate mercury levels.

These questions were considered by the Mercury in Fish and Wildlife Task Force, which was appointed by the governor of Florida in late 1989. The task force ultimately approved a report calling for a broad range of environmental studies that would attempt to find answers to mercury-related questions. At that time, there were few precedents for the concept that air quality could exert a significant influence on surface water quality. In 1992, however, the District, the FDEP, and the USEPA prepared a comprehensive study plan that called for the evaluation of both air and watershed sources of mercury to the Everglades.

A complementary study of the accumulation of mercury in dated sediment cores from the Water Conservation Areas (WCAs) and the Everglades National Park (ENP or Park) revealed that the rate of mercury accumulation in Everglades soils at the top of the cores, i.e., circa 1992, was approximately six times higher than the core strata representing 1900 (Rood et al., 1995) (**Figure 2B-2**). This study demonstrated that the Everglades was contaminated by mercury. At that time, neither the sources of mercury nor the transport systems delivering it were evident.

Despite the remaining uncertainties regarding the sources and routes of mercury contamination in the Everglades, the two studies illustrated above confirmed that, in terms of its mercury budget, the Everglades is a system contaminated by anthropogenic activities principally mediated by atmospheric transport and deposition.

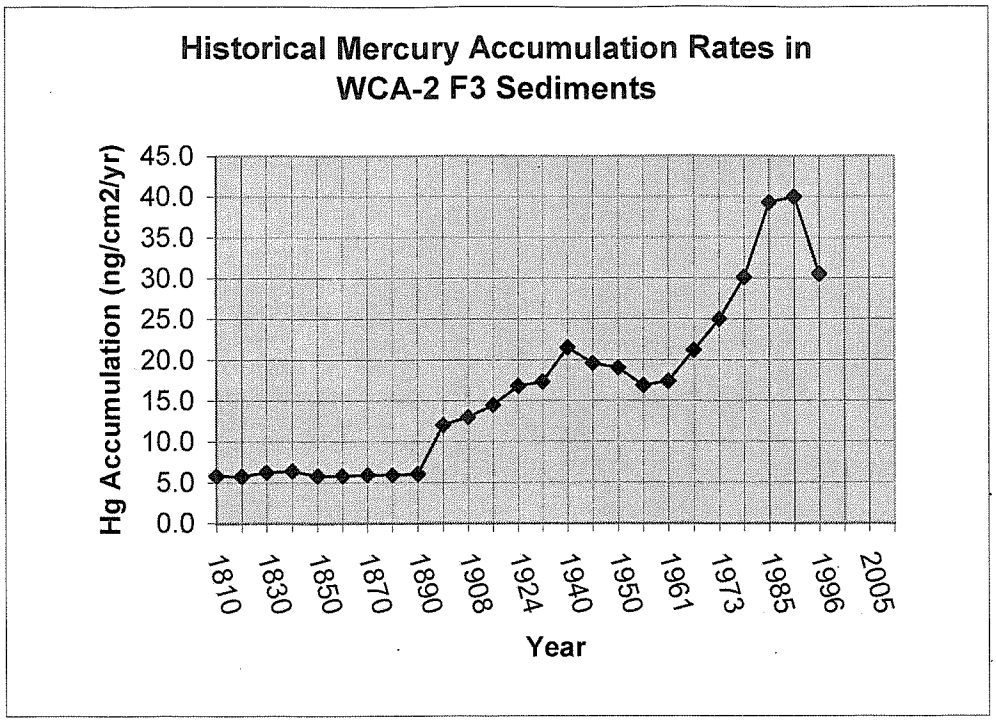

Figure 2B-2. Historical trends of mercury accumulation in Everglades soils. New event analyses are under way to confirm downward trends in recent years.

Because atmospheric deposition of mercury is the dominant source of mercury to the Everglades (**Figure 2B-3**), the FDEP has pursued pollution prevention and emissions controls as having the greatest likelihood for controlling the mercury problem. Major reductions in mercury use and emissions in southern Florida have been achieved, thereby hopefully decreasing the delivery of atmospheric mercury to the Everglades. Findings from both environmental monitoring and computer models suggest that the control of atmospheric sources of mercury can have positive benefits for the EPA. The elimination of mercury from commercial and industrial products and processes since the late 1980s has reduced mercury emissions from municipal waste incinerators and other sources in South Florida.

Monitoring over the last decade suggests that these lower emissions have produced a corresponding reduction in mercury burdens of Everglades fish and wading birds. Environmental models developed by the South Florida Mercury Science Program (SFMSP) relate fish mercury levels to the amount impinging on the Everglades. These models show that the control of mercury emissions should significantly alleviate the overall Everglades mercury problem within one or two decades.

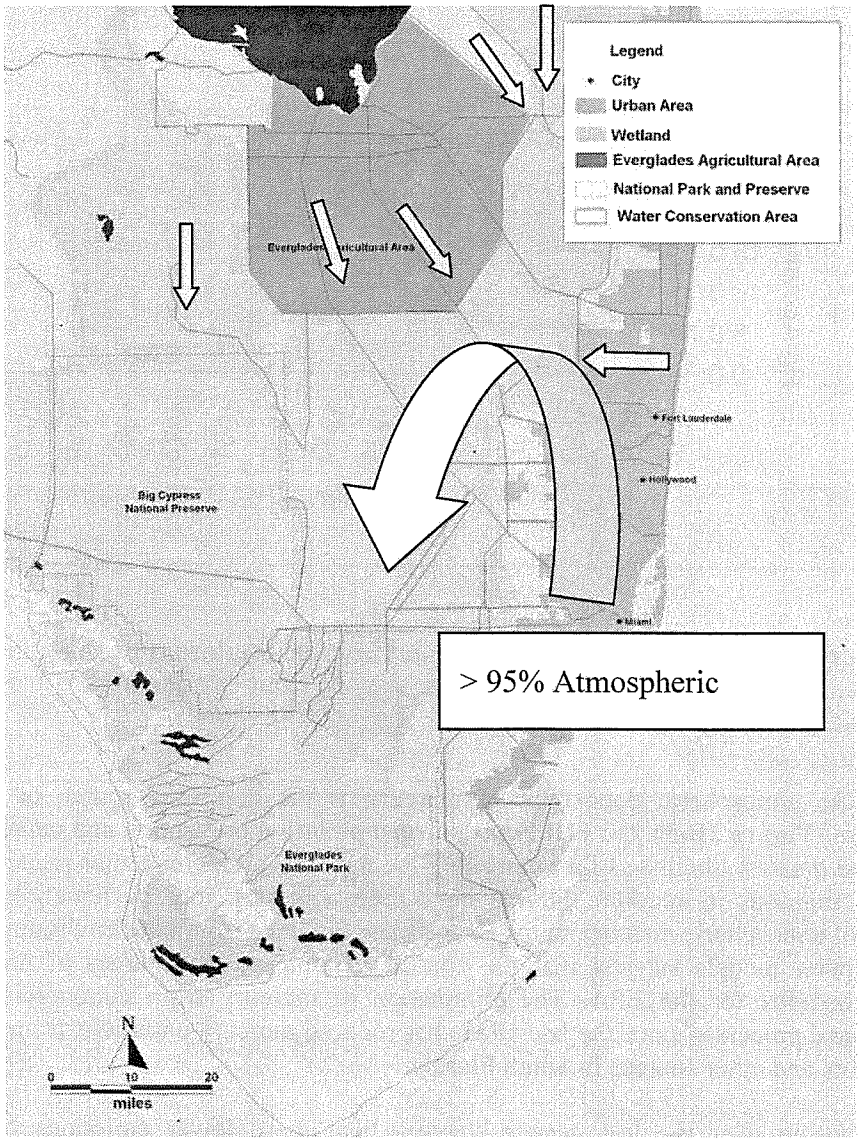

Figure 2B-3. Comparison of mercury inputs via surface water inflows versus atmospheric deposition to the Everglades Protection Area (EPA).

Another important question about atmospheric mercury is that of the nature its sources. The primary transport regimes relevant to South Florida are local scale (i.e., transport times of approximately one day, or about 100 kilometers [km]), regional scale (i.e., transport times of approximately one week or about 1,000 km), and global scale (i.e., transport times of weeks, dispersing over much of the globe) (Expert Panel, 1994). Florida is largely disjunctive from the regional background of emissions that dominates the U.S. mainland, and data suggest a contribution to the Everglades from regional sources within the southeastern U.S. of between 5 percent (Atkeson et al., 2002) to 29 percent of total deposition (Guentzel et al., 2001). Analysis suggests that local scale sources represent at least half of the total atmospheric mercury contribution to the Everglades (Atkeson et al., 2002).

COMPREHENSIVE SOURCE REDUCTION

Finding remedies to address the problem of excessive mercury in fish has been limited by predictive knowledge of its causes. However, one general aspect of the solution is clear. That is, mercury emissions to the environment should be limited to the extent allowable by available information and technology. The FDEP has vigorously pursued the following approaches to address this issue:

- **Pollution Prevention.** The 1993 Florida Solid Waste Management Act required elimination of mercury from some commercial products to reduce the mercury content of wastes. The act bans the use of mercury in packaging materials, prohibits incineration of mercury-containing devices, promotes recycling of such products, and phases out the use of mercury-containing batteries. Presently, international treaties within North America and between North America and Europe seek further reductions in mercury use.
- **Waste Disposal.** Hazardous waste regulations have been tightened to require stricter control of mercury-containing wastes. Proper disposal minimizes long-term releases of mercury into the environment. A side effect of stricter regulation of mercury discharges has been to encourage elimination of mercury from commercial products and industrial processes.
- **Emissions Control.** A Florida emissions inventory found that the major sources of atmospheric mercury were municipal solid waste combustors, medical waste incinerators, and electric utility boilers. The FDEP adopted the first U.S. regulations limiting emissions of mercury from waste combustors and has adopted USEPA regulations for medical waste incinerators. Solid waste combustor emissions controls are in place on most facilities in Florida, and Medical Waste Incineration (MWI) emissions have dropped sharply as the industry has moved away from incineration in response to emissions regulations. Emissions in Florida from each of these sectors have dropped more than 90 percent since 1990.

THE AQUATIC CYCLE OF MERCURY – BIOTRANSFORMATION AND BIOACCUMULATION

The pathways of mercury accumulation in fish and wildlife are complex. Although inorganic forms of mercury dominate its environmental cycle, a proportion can be transformed into methylmercury in the sediments of water bodies. Methylmercury is primarily produced by sulfate-reducing bacteria (SRB), naturally present in the sediment where oxygen is absent but sulfate is present. These bacteria take up inorganic mercury and convert it to methylmercury as an incidental byproduct of their normal life processes. Other microorganisms living in the sediments

or overlying water readily absorb methylmercury much faster than they excrete it. As other organisms feed on these microorganisms, methylmercury becomes progressively more concentrated at each higher level of the aquatic food web. This process is known as bioaccumulation and results in a buildup of methylmercury at each level of the aquatic food chain. In larger fish, levels of methylmercury may bioaccumulate as much as several million times higher than in the surrounding water. In sufficient doses, methylmercury is toxic to the brain, liver, kidney, and immune system of wildlife and humans and can have adverse effects on egg and fetus development.

Many soil, water quality, and biotic factors directly or indirectly influence methylmercury production. For example, while sulfate is required for microbial methylmercury production, high sulfate levels tend to inhibit production. Drought and fire can increase the production of methylmercury by changing the proportions of sulfur forms in the soil, which can worsen the mercury problem, at least locally over the short term. A better understanding of sulfur's role in mercury accumulation at sites with different levels of nutrient enrichment will permit agencies to evaluate the potential for minimizing the mercury problem through the management of water and its constituents.

If control of local emissions of atmospheric mercury is not sufficient to manage the Everglades mercury problem, then it might be possible to reduce the mercury problem through management of water quality and quantity. This approach would make environmental conditions less favorable for the production of methylmercury. Management of marsh fire frequency, hydrologic patterns, and water constituents, most importantly sulfate, may provide a means for such mitigation. With either approach, less methylmercury would be available, making the accumulation of toxic amounts in fish and wildlife less likely.

More detailed treatments of the general features of the environmental mercury cycle are presented in the 2000, 2001, and 2002 ECR and in Appendices 2B-2 and 2B-5 of the 2003 ECR.

ROLE OF CARBON CYCLING IN METHYLMERCURY PRODUCTION AND BIOACCUMULATION

The hypothesis has been proposed that a reduction in carbon dioxide fixation (productivity) by Everglades plants will exacerbate the Everglades mercury problem. A reduction in Everglades plant productivity could be a consequence of reducing and restoring Everglades phosphorus (P) concentrations to more natural levels – for example, to the proposed 10 micrograms per liter (μg/L) total phosphorus (TP) concentration standard – resulting in less plant growth and plant biomass.

In some aquatic ecosystems, there is an inverse relationship between aquatic plant biomass and mercury in animals in the aquatic food chain. "Biodilution" is the term used to describe the phenomenon where an increase in plant biomass due to a sustained increase in the limiting factor to plant production (i.e., phosphorus in the Everglades) has the effect of reducing the buildup of methylmercury in the aquatic food chain.

Through the mechanism of biodilution, when methylmercury is present in the water column, an increase in plant production results in uptake and sorption of this methylmercury by an increased biomass of plants. This leads to a decrease in the methylmercury concentration per unit of plant biomass. This, in turn, leads to a decrease in methylmercury exposure to organisms that feed on the plants, a decrease in methylmercury concentrations in plant grazers, a decrease in methylmercury concentrations in their predators, and so on up the aquatic food chain.

Biodilution of methylmercury has been demonstrated for a few deep, temperate lakes where the mechanism is relatively simple – increased phosphorus concentrations produce increased phytoplankton biomass. In these deep lakes, there is no significant means of methylmercury production in the water column, or significant methylmercury contribution to the water column from sediments. In contrast, the Everglades algal community is present primarily as periphyton rather than a planktonic community. Specifically for the Everglades, it has been hypothesized that the Everglades periphyton response to nutrient enrichment is analogous to the lake phytoplankton response; that is, periphyton biomass increases with increasing TP concentrations in the range of 10 to 30 µg/L, thereby causing a biodilution effect. If this hypothesis was accurate, then a reduction in TP concentrations to 10 µg/L, causing a reduction in periphyton biomass, could increase mercury levels in the Everglades food chain. However, it has been shown that periphyton biomass actually dramatically decreases with TP enrichment in that range in sawgrass, wet prairie, and slough environments (**Figures 2B-4** and **2B-5**). Thus, the hypothesized mechanism of biodilution for the Everglades is not evident and does not appear to reflect ecological reality.

Additional evidence that the periphyton biodilution hypothesis is not valid for the Everglades is provided by Simon et al. (1999). These data indicate that there is an increase in the methylmercury concentrations in Everglades periphyton with increasing phosphorus concentrations, and not the decrease that would be expected if periphyton were biodiluting methylmercury.

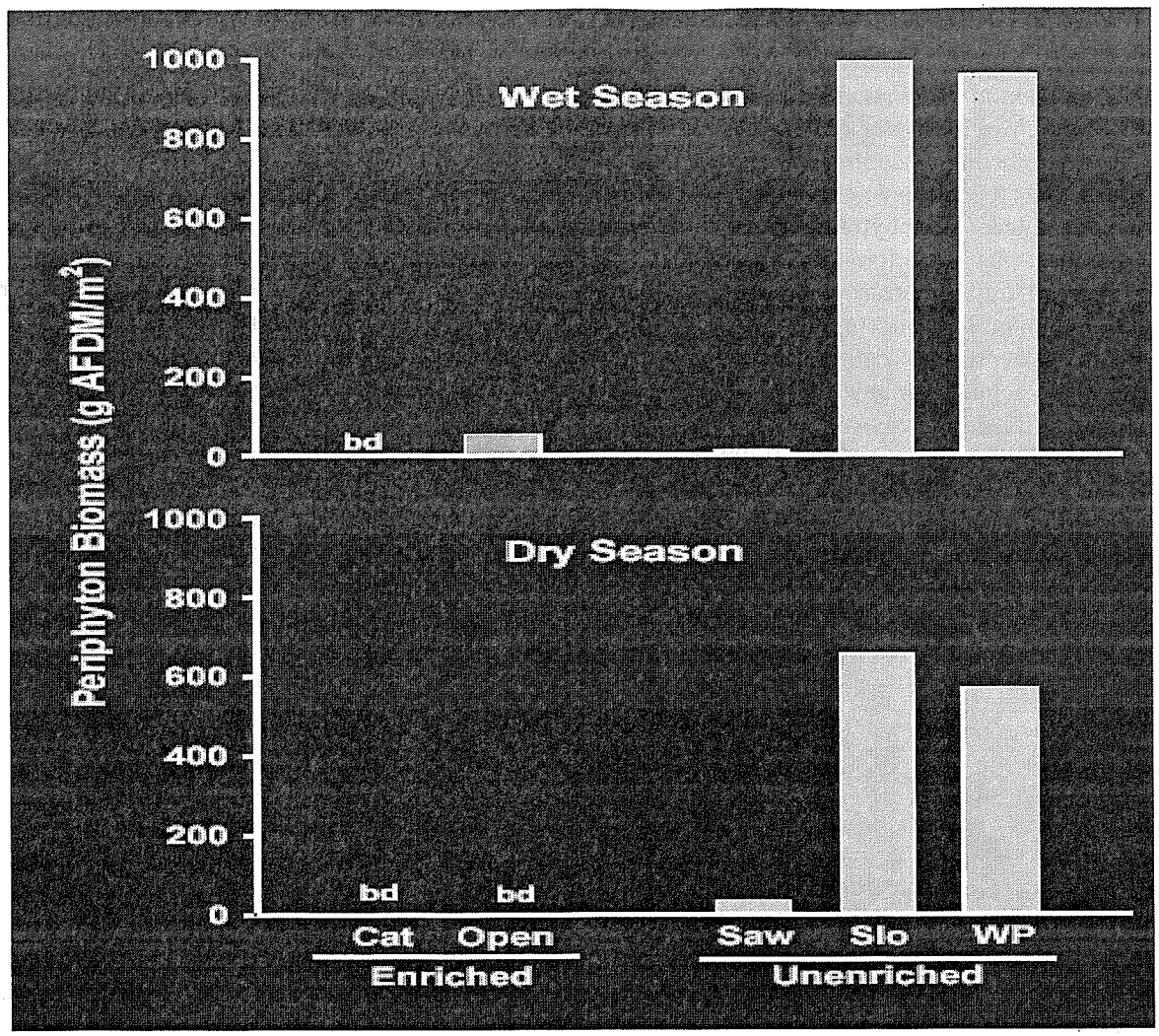

Figure 2B-4. Spatial coverage of benthic and floating periphyton as a function of water column total phosphorus (TP) concentrations (µg/L). This figure was derived from (1) remote sensing data of surface reflectance used to produce areal coverages of different types of plant assemblages, and (2) TP concentrations from monitoring data provided by the District.

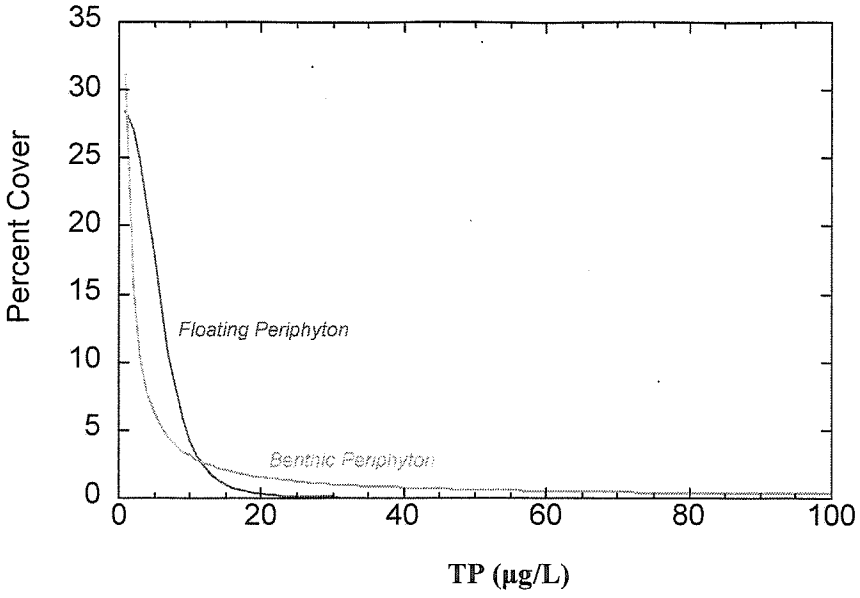

Figure 2B-5. Spatial coverage of benthic and floating periphyton as a function of water column total phosphorus (TP) concentrations (µg/L). This figure was derived from (1) remote sensing data of surface reflectance used to produce areal coverages of different types of plant assemblages, and (2) TP concentrations from monitoring data provided by the District.

ROLE OF SULFUR CYCLING IN METHYLMERCURY PRODUCTION AND BIOACCUMULATION

In surface waters, sulfur exists mostly as sulfate (SO_4^{2-}). Sulfate is not an especially reactive chemical species and it would be relatively innocuous in the Everglades, except for the fact that sulfate is essential for bacterial sulfate reduction (Orem et al., 2003). Bacterial sulfate reduction is the main microbial process responsible for the conversion of inorganic mercury to methylmercury. Conversion of inorganic mercury to methylmercury is the proximate cause of the Everglades mercury problem because methylmercury is much more toxic and biomagnifies much more strongly than inorganic mercury, with fish bioaccumulation factors ranging up to 10 million. Elevated methylmercury concentrations are responsible for about 1 million acres of the Everglades/Big Cypress being under an advisory for fish consumption.

Sulfate entering the Everglades in canal discharge, in combination with the "new" mercury entering the ecosystem predominantly from atmospheric deposition, controls the magnitude and distribution of methylmercury production in the Everglades sediments; sediments are the principal site of methylmercury production by SRB.

The production of methylmercury in Everglades sediments shows distinct geographic patterns. Methylmercury concentrations and methylation rates in sediments are maximal in the central Everglades (WCA-3A) and minimal in the northern, eutrophic areas. The distribution of methylmercury production in the Everglades is not explained by differences in atmospheric deposition of mercury, as deposition is relatively constant (though high) over the entire Everglades. Instead, the distribution of methylmercury is explained by complex biogeochemical interactions between sulfur and mercury. Increasing sulfate concentrations stimulate sulfate reduction and methylmercury production. However, when these sulfate concentrations get too high, buildup of sulfide inhibits methylmercury production. Sulfide is an end product of bacterial sulfate reduction (**Figure 2B-6**).

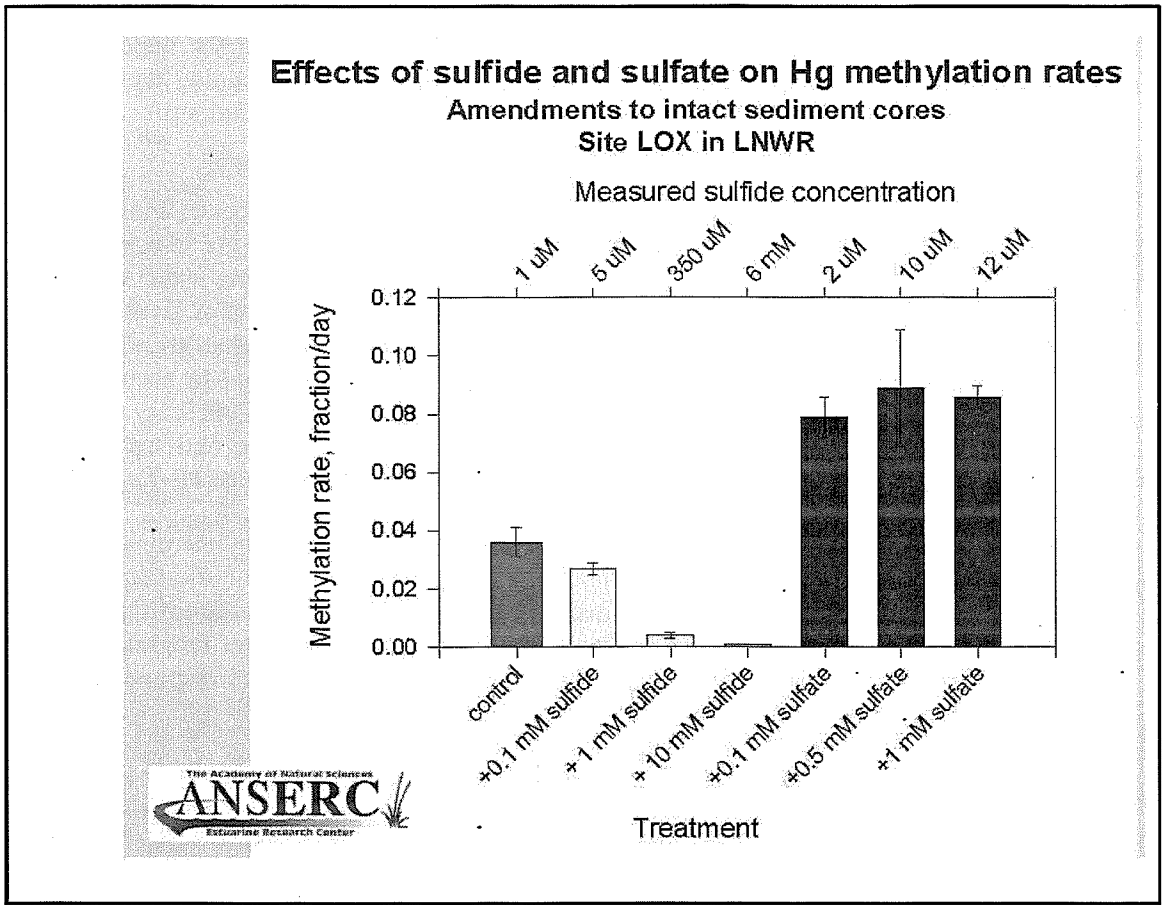

Figure 2B-6. Effects of sulfide and sulfate on Hg methylation rates (C. Gilmour, ANSERC, personal communication).

The distribution of methylmercury in the Everglades is consistent, with the production of methylmercury being highest in areas where bacterial sulfate reduction is stimulated by moderate increases in sulfate concentration from canal runoff, so that sulfide levels in sediment porewater remain relatively low (i.e., where sulfate and sulfide levels are optimal).

Sulfate concentration distributions and sulfur isotope data suggest that the major source of sulfate contamination to the Everglades ecosystem presently is canals draining the Everglades Agricultural Area (EAA); sulfur isotope data are consistent with agricultural sulfur used in the EAA being a major source to the EPA (Bates et al., 2002).

The northern Everglades is heavily contaminated with sulfate with concentrations up to sixty times greater than background levels. The highest concentrations of sulfate are in canal waters in the EAA and in marsh areas near canal discharge sites. The resulting excess in sulfide concentrations suppresses methylmercury production. While in the northern Everglades high sulfur concentrations co-occur with high phosphorus concentrations, mechanistically, sulfur is significantly more important with regard to methylmercury production and to accumulation in fish. Generally, porewater sulfide concentrations are the best predictors of mercury methylation rate and methylmercury concentration in Everglades sediments. Sulfide and methylmercury concentrations are inversely correlated across the northern Everglades (**Figure 2B-7**).

While porewater sulfide concentrations are the best predictors of methylmercury production rates and concentrations in Everglades sediments, methylmercury concentration in Everglades sediments correlate very well with methylmercury concentrations in mosquitofish (*Gambusia spp.*). In turn, USEPA Regional Environmental Monitoring and Assessment Program (REMAP) data show that elevated levels of methylmercury in mosquitofish correspond with high methylmercury concentrations in Everglades wading birds.

Methylmercury concentrations in Everglades fish and wading birds have declined by at least 60 percent in recent years, most probably because of the mercury source reductions and decreased mercury emissions to the atmosphere from municipal solid waste and medical waste incinerators. Atmospheric deposition estimates for mercury (as $\mu g/m^2/yr$) obtained from sediment cores at several Everglades sites from about 1990 to 2001 are presented in **Table 2B-1**.

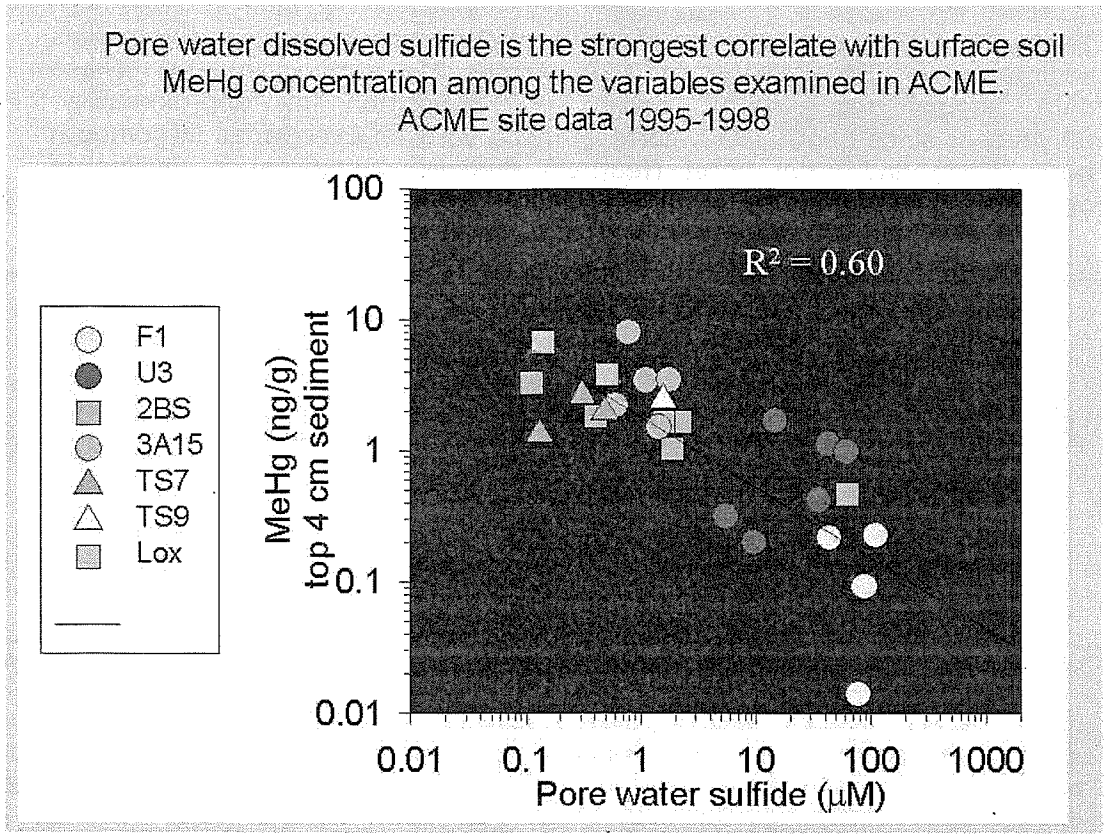

Figure 2B-7. Correlation between porewater dissolved sulfide and surface soil MeHg concentrations from ACME site data from 1995 to 1998 (C. Gilmour, ANSERC, personal communication).

Table 2B-1. The average rate of mercury (Hg) accumulation in Everglades sediments was 54 $\mu g/m^2/yr$ ca. 1990 versus 21 $\mu g/m^2/yr$ in 2001. These data suggest an overall decline in deposition of approximately 60 percent since about 1990, corresponding with an Everglades largemouth bass (fillet) and great egret (feather) mercury concentration decline of approximately 60 percent* from the mid 1990s to 2001.

Sampling Location	Hg Accumulation Rate ca. 1990 ($\mu g/m^2/yr$)	Sampling Location	Hg Accumulation Rate in 2001 ($\mu g/m^2/yr$)
WCA-1	79	ENR Project	21
WCA-2	59	NA	--
WCA-3	39	Andytown	24
ENP	40	ENP	18

Source: Rood et al., 1995; NADP MDN, 2002 (Online at http://nadp.sws.uiuc.edu/mdn).

Note: *This estimate was based on the geometric mean of Hg concentrations in great egret feathers for all active colonies for each year. Because of the high Hg variability among colonies, and to conform to protocols used for many other Everglades analyses, a geometric mean is preferred, resulting in an estimated decline of 60 percent.

Despite these mercury declines in Everglades biota, there is no reason for complacency, and reason to be concerned about future sulfate inputs to the Everglades from agricultural operations, stormwater, and groundwater including Aquifer Storage and Recovery (ASR) sources. Largely in response to sulfide and sulfate concentrations, methylmercury production rates vary by almost two orders of magnitude across the Everglades. This variation is far greater than that due to variation in atmospheric deposition of mercury across the Everglades. As such, the management of sulfur may be an important mechanism for controlling the mercury problem in the future.

Presently, the sulfate contamination plume from the EAA reaches as far south as the middle of WCA-3 as well as into Shark River Slough, where sulfate concentrations may now be optimal for methylmercury production. Given the effect of the EAA sulfate plume on the Everglades, there is reason to be concerned about future sulfate inputs to the Everglades. As such, there is reason to begin to predict (model) the effects of CERP hydrological restoration alternatives as well as other sulfur sources on future sulfur distribution, methylmercury production rates, and methylmercury bioaccumulation across the ecosystem.

Based on the information presented above, the following can be concluded:

1. Biogeochemical interactions between sulfur and mercury explain the variation in methylmercury production rate in sediments across the Everglades, and methylmercury concentrations in fish and wading birds.
2. Sulfate contamination originating from the EAA plays a key role in regulating the concentration and distribution of methylmercury in Everglades sediments and fish.

3. Reduction of mercury sources to the Everglades has successfully reduced mercury levels in fish and wildlife and this remains a viable management option, with sulfur input reduction also being an important management option; phosphorus is not an effective or ecologically responsible control agent for the Everglades mercury problem.

RESPONSE OF THE NATURAL SYSTEM TO SOURCE REDUCTIONS

According to data reported in early 1989, small numbers of largemouth bass collected at three Everglades locations (L-38A, L-35B, and L-67A) averaged nearly 2.5 milligrams per kilogram (mg/kg) of total mercury in the edible fillet. These findings were promptly confirmed and led to the Florida Department of Health issuing an unprecedented health advisory to fishermen to cease consumption of largemouth bass from those areas. Subsequent sampling showed that mercury problems extended to many other Florida waters. Since that time, the Department of Health, the Florida Fish and Wildlife Conservation Commission (FWC), and the FDEP began collaborating on annual collection and testing of fish from five sites in Florida (including the L-67 site) to determine whether the trend of mercury concentrations in fish is increasing or decreasing.

Subsequent monitoring of mercury in fish and wildlife in the Everglades and other areas in Florida has yielded annual information on mercury body burdens in nestlings. This information can be similarly examined for temporal trends in an update of the corresponding figure (Figure 2B-14) from the *2003 Everglades Consolidated Report*, which shows an overall decline in mercury concentrations in largemouth bass, with year-to-year variability (**Figure 2B-8**). **Figure 2B-9** shows a similar trend with the mercury concentrations in the feathers of great egret nestlings decreasing over time. However, it has been difficult to determine how these trends in mercury levels in biota compare to trends in the mercury load to the Everglades or to emissions trends in the United States or in Florida. This difficulty is caused by the limitations of available data, models, and other tools to model the local, regional, and global scales of air-pollutant cycling.

Atmospheric deposition trend monitoring of rainfall mercury deposition began in South Florida with the establishment of four monitoring sites of the Florida Atmospheric Mercury Study (FAMS) adjacent to the Everglades in 1994 and 1995 and continuing through 1996. In 1995, the FDEP sponsored the installation of one of the first Mercury Deposition Network (MDN, a sub-network of the National Atmospheric Deposition Program [NADP]) sites at the Park's Beard Research Center, co-located with the FAMS site. The sites, operated side-by-side by their respective groups for 15 months, established that comparability was excellent. After completion of the FAMS project, the District assumed responsibility for the Park's MDN site and established two others (Andytown and Everglades Nutrient Removal [ENR] Project) to ensure continuity of long-term trend monitoring of atmospheric mercury wet deposition to the Everglades. Recent meta-analysis of mercury wet deposition from both FAMS and MDN does not indicate any significant temporal trend. However, it is likely that emissions reductions occurred before the monitoring began in 1994. It is also likely that data variability will hamper attempts to detect trends in deposition data.

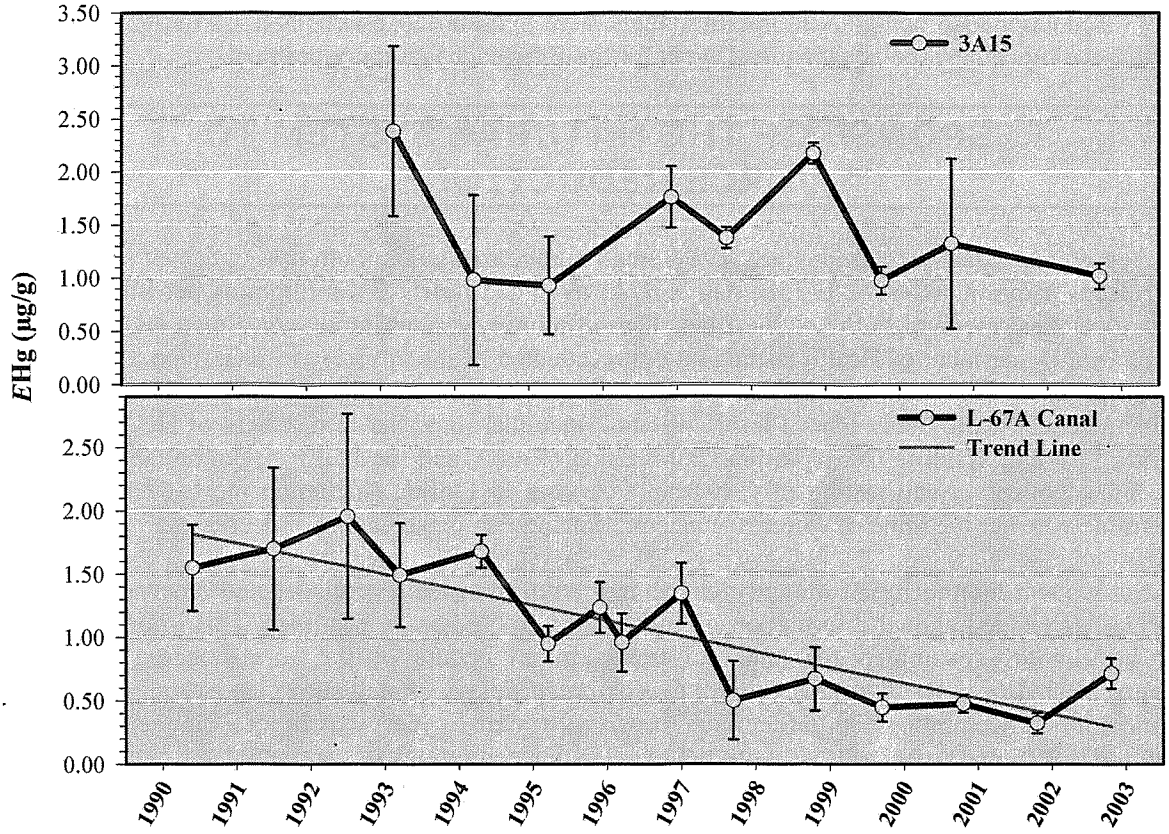

Figure 2B-8. Mercury concentrations (µg/g, with adjusted least square means) in fillets of age-standardized largemouth bass in the Everglades L-67 canal and at WCA-3A-15, the mercury "hot spot" (Lange et al., 2003).

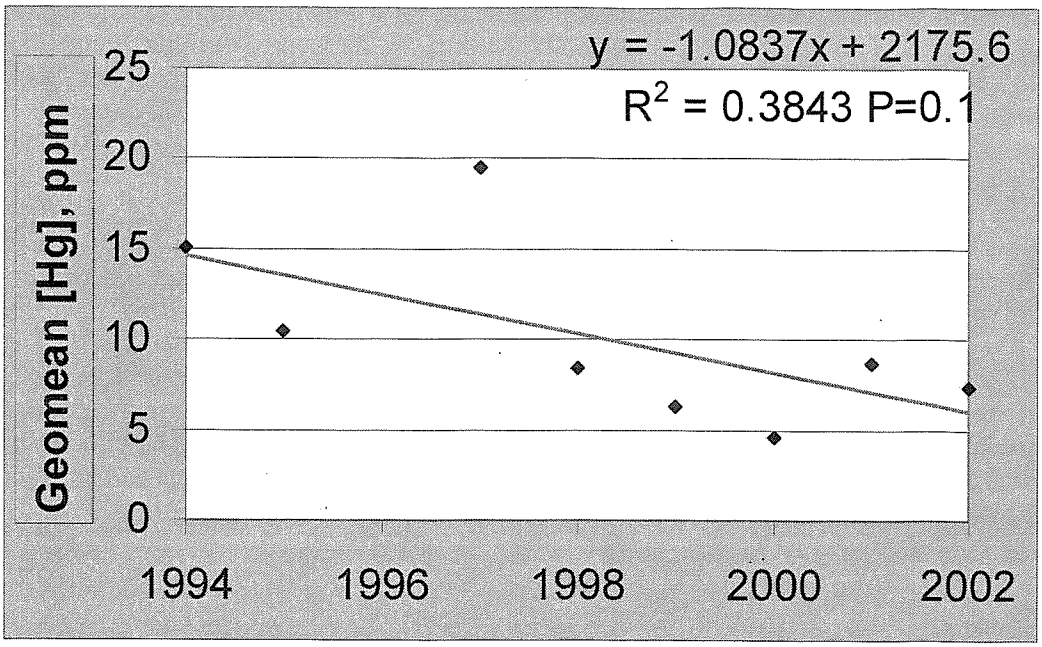

Figure 2B-9. Geometric mean concentrations of mercury in great egret chick feathers collected from active Everglades colonies each year from 1994 through 2002. Mercury exposure to great egret chicks has declined approximately 60 percent over this period.

Data from about 1994 to the present suggests that mercury levels are declining in Everglades fish and birds. This apparent trend is consistent with the timing and extent of a national trend in the mercury content of incinerated waste in the United States. While this evidence is preliminary, it is consistent with the time lag predicted by modeling for a decline in atmospheric deposition resulting from decreasing amounts of mercury emitted by air sources within South Florida. Further declines in wildlife mercury exposure from these control measures are possible. Additional controls are also possible and could produce a greater reduction in exposure. With existing evidence, it is premature to rule out the possibility that emissions controls can further reduce exposures in the entire Everglades, including the impacted areas.

As presented in Appendix 2B-4, a new historical analysis of the long-term trends of mercury in wading birds was completed in 2003 (**Figure 2B-10**). This illustrates a trend concordant with the trend of mercury accumulation shown in **Figure 2B-2**.

It is anticipated that the monitoring of mercury trends in atmospheric deposition, fish, and wading birds will continue indefinitely. It is likely that much of the emissions reduction responsible for this apparent trend occurred prior to the initiation of mercury monitoring in wet deposition in South Florida. Further work, consisting of hind-casting emissions and examination of new sediment cores, is underway to test this hypothesis.

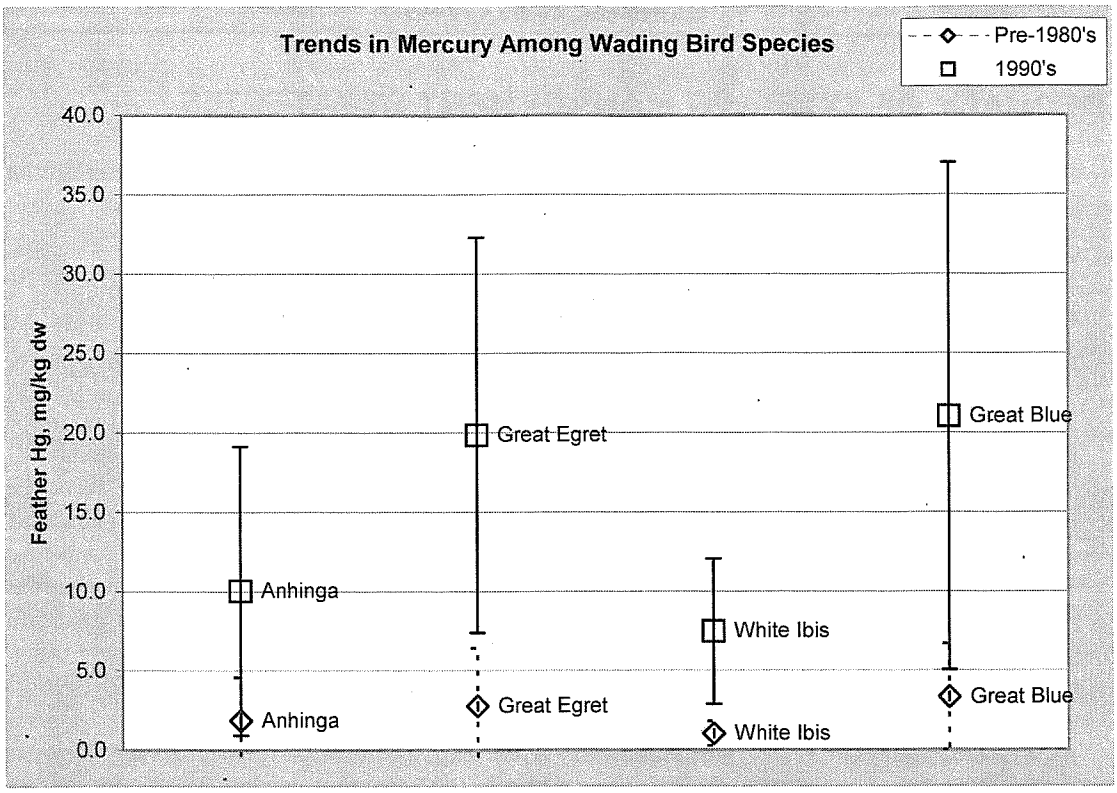

Figure 2B-10. Historical comparisons among wading bird species in mercury content of feathers through time. Samples collected from North American museums for specimens tagged with a South Florida origin.

CONCLUSIONS

ADEQUACY OF EXISTING MANAGEMENT STRATEGIES

The public and private agencies comprising the South Florida Mercury Science Program have worked effectively to achieve the following:

1. Describe and define the mercury problem in the Everglades
2. Identify and quantify the sources and causes of the mercury problem
3. Develop and implement appropriate environmental controls to abate the mercury problem and monitor the effectiveness of the abatement measures

A comprehensive program of monitoring, modeling, and research has broadened an understanding of the sources and causes of the mercury problem. The results have been incorporated into sophisticated environmental models that predict the Everglades will respond to decreases in atmospheric mercury deposited into the marshes in a direct, nearly one-to-one relationship. More encouragingly, the models suggest that significant benefits from decreased mercury loading should be seen in less than a decade, with full benefits within a generation. Current monitoring trends for mercury within the Everglades system indicate the beginning of positive results of pollution prevention and control efforts that were initiated in the mid 1990s.

As a result of a series of international, North American, and Florida initiatives, mercury usage in North America has declined by approximately 90 percent since 1990. In addition, environmental controls have been developed and implemented for Medical Waste Incineration (MWI) and Municipal Solid Waste Incineration (MSWI), both of which have resulted in emissions declines in excess of 95 percent for each source sector. At the time of publication of the *2003 Everglades Consolidated Report*, there was a pending decision with regard to control policy by the USEPA. The USEPA had made its decision under the Clean Air Act Amendments of 1990 to regulate mercury emissions from coal- and oil-fired utility boilers, and was to develop regulatory specifics by the end of 2003. The proposed Clean Skies Initiative has since superceded promulgation of the Maximum Achievable Control Technology (MACT) standards for mercury from utilities under the Clean Air Act Amendments of 1990. At this time, it is not known what direction will be taken on national mercury emissions control policy with regard to the limits of mercury emissions from this industrial sector.

The atmospheric mercury studies conducted by the FDEP and its collaborators in the SFMSP have been completed in close collaboration with the USEPA to ensure rapid transfer of new technologies and information into the national program. The FDEP is pleased to have provided useful information to the USEPA and other federal agencies and has thereby assisted and promoted a sound scientific basis for policy decisions.

The multiagency approach to the mercury problem in South Florida has been a notable example of the successful marriage of science and policy. This comprehensive, long-term approach has enabled Florida to become the model for addressing a complex, multimedia environmental problem.

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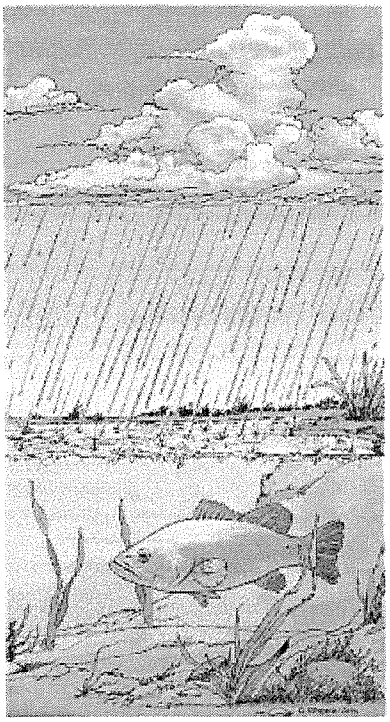
Appendix J:
Environmental Monitoring for Mercury in Massachusetts
Studies Status Report1994-2004



ENVIRONMENTAL MONITORING FOR MERCURY IN MASSACHUSETTS

STUDIES STATUS REPORT 1994 - 2004

November 2004

Office of Research and Standards
Massachusetts Department of Environmental Protection
1 Winter Street
Boston MA 02108

Table of Contents

Executive Summary

The Commonwealth of Massachusetts has been conducting studies on understanding the dynamics and distribution of mercury in tissues of freshwater fish for two decades. The primary goal of the early work was to identify fish populations that posed unacceptable health risks to fish consumers. In 1994, the first comprehensive statewide examination of mercury in freshwater fish began. This study was followed in 1999 by a study of fish mercury concentrations in an area of the state thought to have regionally high atmospheric deposition of mercury. As part of continuing efforts to elucidate the status of the Commonwealth's freshwater fish populations with respect to mercury contamination, several additional studies have been carried out. These studies were designed to provide insight into long-term trends in freshwater fish mercury concentrations, to estimate the magnitude of seasonal variability in mercury measurements, to document the comparative differences in mercury partitioning in lake food webs, to summarize the state of knowledge of mercury in other wildlife, and to begin to discern the historical picture of mercury deposition to freshwater sediments. The data generated from the studies on mercury concentrations in edible tissue of popular freshwater fish permit more widespread screening of the Commonwealth's lakes for potential health threats posed by eating contaminated fish. Health threats are addressed through the issuance of fish consumption advisories by the Massachusetts Department of Public Health.

In 2001, a long-term monitoring protocol was developed for fish tissue mercury studies to enable charting of temporal changes in fish tissue mercury concentrations, and to determine whether recently imposed mercury emissions controls on municipal solid waste incinerators correlate with lower mercury in fish. A component of the study included intensified seasonal sampling in a subset of long-term monitoring lakes to document the magnitude of seasonal variation in fish tissue mercury concentrations. This information will be used to improve the designs of future fish sampling efforts and to provide a perspective on the scale of natural variability in tissue mercury concentrations for comparison with other sources of variation.

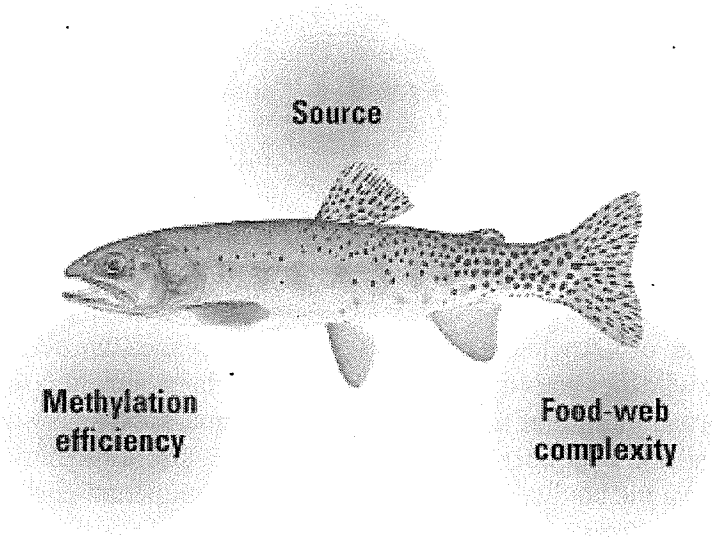
Previous work revealed that spatially proximate lakes similar in physical features could have fish with substantially differing amounts of mercury. In order to examine the underlying reasons for these differences, we selected two nearby similar ponds in northeastern MA for a comparative analysis of the food web concentrations of mercury and the environmental characteristics of each pond.

Piscivorous birds are at risk from mercury exposure via the food chain. Loons have been a focus of attention in New England for ecological and aesthetic reasons. A first step towards addressing threats of mercury to wildlife in Massachusetts is to have an understanding of the state of knowledge of mercury in indigenous non-fish vertebrates in the Commonwealth. A

compilation of this information for Massachusetts and recommendations for future monitoring has been assembled.

To provide a historical perspective to our work, a limited study of mercury deposition to the aquatic environment of northeastern MA was conducted. Following a workshop held to consult with the research community on issues of sediment core analysis such as interpretation and costs, an analysis of the historical rate of mercury deposition to the bottom sediments of a freshwater lake in an area of the state having regionally high fish mercury concentrations was conducted, using isotopic dating of a sediment core.

Knowledge of the major sources of variance in fish mercury data can be used to improve the precision of fish tissue mercury studies. We conducted several studies of sources of variance in fish tissue mercury. Tissue moisture experiments were conducted to determine the variability due to sample preparation. A study of fish holding time was done to determine the stability of mercury in frozen fish samples over time. An investigation of statistical methods to compensate mathematically for the correlation of fish size with mercury, and the statistics to determine scientifically acceptable sample sizes were critical parts of the mercury studies.



Overview of Studies

The Division of Water Pollution Control at MA DEP began testing fish for contaminants in 1984. By then conventional water pollutants from point sources had been brought under control, and attention was turned to the evaluation of impacts from toxic substances. The initial fish testing programs developed into an Interagency working group that involved DEP's Office of Research and Standards, Wall Experiment Station, the Division of Fish and Wildlife, and the Department of Public Health. Members of the public were able to request fish testing at locations of concern through this program. If fish were found to contain contaminants, a fish advisory would be issued for the location by MA DPH. Test results showed a need for more comprehensive sampling to establish patterns and trends in fish contamination across the state.

Baseline Study of Fish Mercury

Fish reflect elevated mercury inputs to the environment. Approximately 40% of the rivers and lakes in Massachusetts sampled since 1983 are subject to fish consumption advisories as a result of mercury contamination of edible fish muscle.

When the extent of mercury contamination of Massachusetts' freshwater fishery resources became apparent in the early 1990s, MA DEP conducted a study to determine the distribution of mercury in freshwater fish tissue in non-source-impacted, largely rural Massachusetts lakes. That study sought to define a baseline for future studies and to identify possible environmental factors associated with mercury in largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), and brown bullhead (*Ameiurus nebulosus*).

Fish Mercury Research in Northeastern Massachusetts.

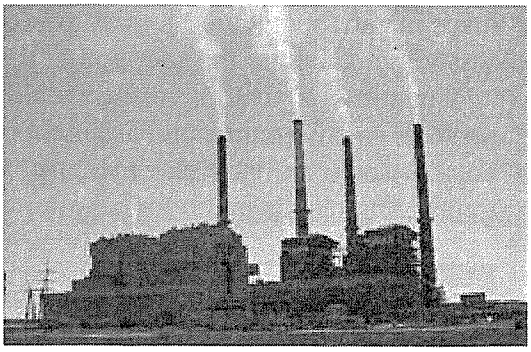
In 1994, fish from a few of the lakes in the northeast part of the State were sampled as part of the State's interagency fish toxics surveillance program. The area had the State's highest concentration of point sources of atmospheric mercury emissions in the last two decades of the twentieth century: three municipal solid waste combustors and a medical waste incinerator. Some lakes were identified as having fish with tissue mercury concentrations greater than 0.50 mg/kg, the concentration above which the Massachusetts Department of Public Health issues fish consumption advisories. More restrictive advisories are issued for concentrations greater than 1 mg/kg.

In 1998 MA DEP initiated new municipal solid waste combustor rules that included stringent mercury emissions control regulations to lower mercury emissions up to 95%. A study of mercury in fish in lakes in and around the Merrimack Valley was initiated before the adoption of the new controls, so that the results would serve as an environmental baseline for comparison with fish tissue mercury monitoring results in the future, after the

emissions reductions. The study would also determine the need for additional consumption advisories, clarify possible spatial patterns in the occurrence of higher fish mercury concentrations, and allow comparison of fish contamination in a high mercury deposition area to more rural areas in Massachusetts and to regional New England data.

Mercury Initiative.

The New England Governors and Eastern Canadian Premiers adopted the Regional Mercury Action Plan in June 1998. The Plan takes an integrated, comprehensive approach that incorporates mercury pollution control and pollution prevention of air, water and land. The goals of the multi-agency Action Plan are to reduce New England mercury emissions by 50% as of 2003, by 75% as of 2010, and the virtual elimination of mercury emissions over the long term. A regional task force undertakes actions in emission reduction, source reduction, waste management, outreach and education, and monitoring and research.



The overall objective of the monitoring and research action category is to improve understanding of mercury sources and the impact of mercury contamination on public health and ecosystem health. In addition, as the emissions control and other action categories commence, monitoring and research will track the response of the environment to the action initiatives. Key indicators for tracking the progress and success of the Regional Mercury Action Plan are studies of mercury in fish, wildlife, and lake sediments.

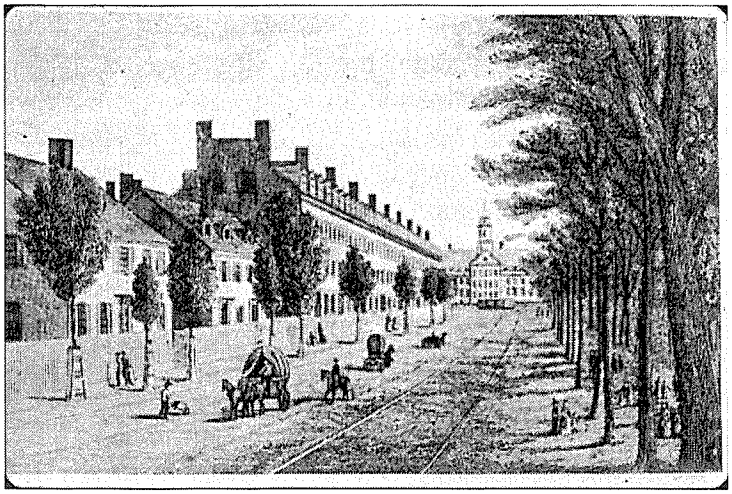
Long Term Monitoring Program.

Permanent locations for fish tissue mercury monitoring are required for documenting the manifestation of trends resulting from mercury reduction efforts. Established monitoring sites would provide several pieces of valuable information to help understand fish mercury trends. Resampling over time will provide a consistent, long-term record of mercury concentrations in fish across the state. The data will represent an indicator of the responses of the environment to changes in mercury inputs resulting from regional and national mercury emissions control efforts. The information will also characterize year-to-year and seasonal variation in fish mercury concentrations.

An accurate assessment of the causes of variation has been a major focus of the fish research program. Statistically robust sample sizes were developed to allow detection of geographic variation in a relatively small state. Sources contributing to the total variance were thoroughly investigated in the course of the research.

To document trends in time and space, analysis of sediment cores was initiated,

after consultation with the research community. Isotopic dating of a sediment core from a Merrimack Valley lake established a record of the history of mercury deposition, a history of increased deposition that was triggered by the damming of the Merrimack River, and closely followed industrialization in Massachusetts.



Lowell, MA in the late 1800's.

Descriptions of Research Studies.

Title: Fish Monitoring Through Public Requests

Objectives: Massachusetts environmental agencies instituted a program by which the general public may request that fish from a lake or stream be sampled and analyzed for the presence of potentially toxic chemicals. The program screens fish from heavily fished locations for contaminants. If contaminants in the fish exceed health standards, a fish consumption advisory is posted at the waterbody. The program has been expanded to include waterbodies in watersheds as part of systematic watershed assessment.

Background: A growing awareness of the effects of environmental contamination of streams and lakes created an increased public demand for fish toxics monitoring data. Beginning in 1993, a formal protocol and request procedure was made available to the public by the following environmental agencies:

- Massachusetts Department of Environmental Protection
  - Division of Watershed Management
  - Division of Environmental Analysis / Wall Experiment Station
  - Office of Research and Standards
- Massachusetts Department of Public Health, Bureau of Environmental Health Assessment
- Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement

Program Description: An Interagency Committee was formed to conduct the program, and a Memorandum of Understanding was produced by the agencies involved to establish the structure of the Public Request Program. Applications for requesting fish testing at a waterbody were made available to the public, who then submit the request to DEP's Division of Watershed Management.

The Interagency Committee meets annually to prioritize the requests according to agreed upon criteria (fishing pressure and the potential for contamination). Three to five species of fish are collected, representative of the ecological niches in the waterbody, e.g., bottom feeders, water column feeders, and predatory fish. Three to five individuals of each species are composited for analysis. Fish samples are analyzed for arsenic, cadmium, lead, mercury, selenium, PCB arochlors and congeners, and organochlorine pesticides. Additional metals and organics may be analyzed for as necessary.

Summary of Results: Massachusetts' waterbodies are frequently found to be contaminated with mercury. Two hundred thirty six waterbodies have been assessed as part of this program. Ninety-eight of the waterbodies required a fish advisory for mercury contamination. Twenty five waterbodies required fish advisories for PCBs (13 advisories), DDT (6 advisories), chlordane (4 advisories), PAHs or dioxin (1 advisory each). One hundred thirteen locations did not require fish advisories. The Department of Public Health issued a statewide advisory regarding the dangers of consumption of freshwater fish, especially for pregnant women and young children, due to mercury contamination, as a result of the fish testing program.

By screening lakes for mercury and other contaminants in fish, it was found that fish contamination often occurred in lakes with no obvious source of pollution. The fish screening program demonstrated the need for a more directed study of lakes in different ecoregions across the state, using larger sample sizes of individual fish, rather than composites, to improve the ability to detect geographic or environmental differences in the distribution of mercury in fish.

Program Status: The program continues to assess the water resources and suitability of fish for consumption in the Commonwealth.

Cost: Participants in the program are personnel employed at state agencies, and the program is conducted as part of their service. No additional costs or budget are associated with the program.

Work Products:

Reports: A yearly report describing the results of fish analysis is compiled by Robert Maietta, Division of Watershed Management, MA DEP.

Publications: Isaac, R.A., R.J. Maietta, A.S. Johnson, 1992. The role of fish tissue monitoring in evaluating and managing toxic substances: A summary of Massachusetts' Program. Ma Dept. of Environmental Protection, Bureau of Resource Protection, Division of Water Pollution Control.

Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, 1994. Fact sheet on mercury in freshwater fish.

Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, 2001. MDPH Issues New Consumer Advisories On Fish Consumption and Mercury Contamination. Press release.

Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, 2004. Freshwater Fish Consumption Advisory List - April 2004. http://mass.gov/dph/beha/fishlist.htm

Massachusetts Department of Public Health, Bureau of Environmental Health Assessment also issues lake or river specific fish advisories when fish from a waterbody is determined to contain contaminants. The advisories are issued in five languages and are sent to the Boards of Health in the towns where the fish have been collected. Boards of Health are asked to post the fish advisories at the specific waterbody.

Public Presentations: Progress in monitoring Massachusetts Lakes is regularly presented at the New England Association of Environmental Biologists (NEAEB) annual meeting.

Title: Statewide Study of Lakes in Diverse Sub-ecosystems

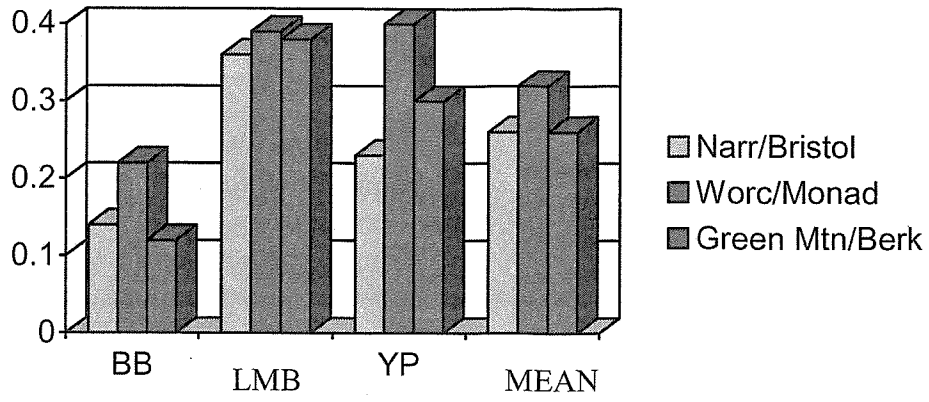
Objectives: The widespread mercury contamination in freshwater fish revealed in the screening program suggested a more comprehensive study was needed to understand the geographic distribution of mercury in fish and to determine what physical or hydrologic features may influence variation in mercury levels.

Background: The fish screening program conducted by three state environmental agencies showed that high levels of fish mercury existed in fish from lakes with no known sources of contamination. Ecologically-based geographic subdivisions had been investigated in some studies as being associated with differences in the bioaccumulation of metals by fish. Trophic status of lakes was also thought to influence mercury bioaccumulation in fish.

Study Description: The sediment, water and 3 species of fish from 24 of Massachusetts' relatively least-impacted waterbodies were sampled and analyzed to determine the patterns of variation in edible tissue mercury concentrations and the relationships of these patterns to characteristics of the sediment, water and water bodies (lake, wetland and watershed areas). Sampling was apportioned among three different ecological subregions and among lakes of differing trophic states, ranging from oligotrophic to eutrophic. We sought to partition the variance to discover if these broadly defined concepts are suitable predictors of mercury levels in fish.

Summary of Results: Average muscle mercury concentrations were 0.14 mg/kg wet weight in the bottom feeding brown bullheads (*Ameiurus nebulosus)* (range=0.01-0.79 mg/kg); 0.31 mg/kg in the omnivorous yellow perch (*Perca flavescens*) (range=0.01-0.75 mg/kg); and 0.40 mg/kg in the predaceous largemouth bass (*Micropterus salmoides)* (range=0.05-1.1 mg/kg). Statistically significant differences in fish mercury concentrations between ecological subregions in Massachusetts existed only in yellow perch, although there was a suggestion of such a relationship in brown bullhead. The productivity level of the lakes (as deduced from Carlson's Trophic Status Index) was not a strong predictor of tissue mercury concentrations in any species. A highly (inversely) correlated environmental variable was pH with yellow perch and brown bullhead tissue mercury. Largemouth bass tissue mercury concentrations were most highly correlated with the weight of the fish (+), the weight (+) and mercury concentrations (-) of yellow perch in the same lake and the magnitude of surface areas, watershed and wetland areas associated with lake (+). These results are generally consistent with existing knowledge of freshwater fish tissue mercury dynamics and are notable for demonstrating spatially correlated differences in tissue mercury concentrations across ecological subregions on a scale less than about 150 miles.

Mercury (ppm) in Fish from Three Ecological Subregions



Project Status: This research project is complete. The results have been used in subsequent studies as a representative baseline of fish mercury in the state.

Cost: $65,000.

Work Products:

Reports: Fish Mercury Distribution in Massachusetts Lakes. Final Report. MA DEP, Office of Research and Standards, May 1997.

Publications: Rose, J., M.S. Hutcheson, C.R. West, O. Pancorbo, K. Hulme, A. Cooperman, G. DeCesare, R. Isaacs, and A. Screpetis, Fish Mercury Distribution in Massachusetts, USA Lakes. *Environmental Toxicology and Chemistry*, Vol. 18, No. 7, pp. 1370-1379, 1999, SETAC.

Public Presentations: Fish Mercury Distribution in Massachusetts Lakes. Presented at the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada, 1995.

Fish Mercury Distribution in Massachusetts Lakes. Presented at the Boston Risk Assessment Group, Cambridge, MA, March 1997.

Title: Merrimack River Valley Fish Mercury Study

Objectives: Fish from 26 lakes in northeast Massachusetts were sampled in order to:

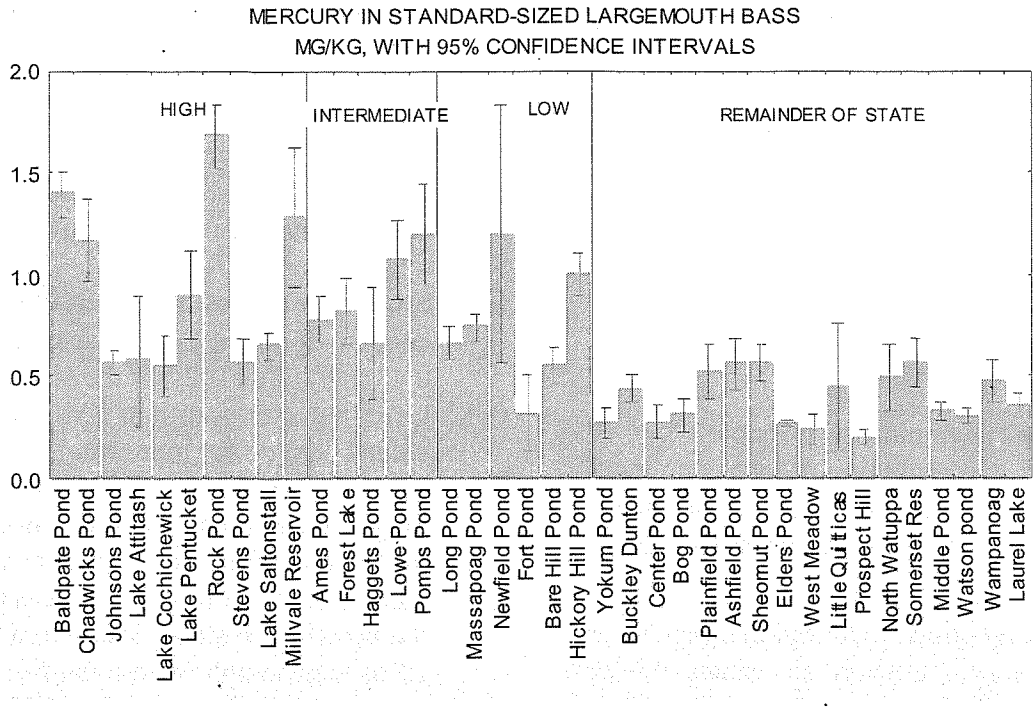
- Determine if human health fish consumption advisories for mercury were necessary;
- Examine the relationships between levels of fish tissue total mercury concentrations in the study area and other regions of the state and country; and
- Examine the possible contribution of local sources of atmospheric mercury to the local fish mercury concentrations.

Background: In a regional report on mercury in the northeast states, this area of Massachusetts was predicted to have the highest level of atmospheric mercury deposition in the northeast U.S., on the basis of atmospheric dispersion modeling of sources of mercury emissions in the U.S. Until recently three municipal waste combustors and one medical waste incinerator were located in this area. The area has a long history of industrialization, with mercury releases occurring as early as the nineteenth century.

Study Description: The study area was delineated into downwind, near-field upwind and far upwind areas based upon prevailing wind patterns vis-à-vis the four incinerators. Largemouth bass (LMB) (*Micropterus salmoides*) and yellow perch (YP) (*Perca flavescens*) were the primary species sampled. Concentrations of mercury in fish tissue were compared with data from elsewhere in the State and between these sub-areas to determine whether any differences could be potentially attributed to the incinerators.

Summary of Results: Mercury concentrations in LMB (mean 0.89 ± 0.43 mg/kg [n=192]) in the study area were in the top fourth of LMB mercury values derived for more rural, non-local-source-impacted Massachusetts lakes in the west, central and southeastern parts of the state. Because of the elevated mercury concentrations, all but one of the lakes in the study design in which LMB were caught warranted fish consumption advisories for LMB (concentrations >0.5 mg/kg). This particular lake was located farthest upwind of the incinerators. In other parts of the state, fewer than 50% of the waterbodies tested in a previous study required fish consumption advisories due to mercury. YP mercury concentrations (mean 0.44 ± 0.21 mg/kg, n=152) were similar to, or slightly greater than those from more rural regions of the state. YP mercury concentrations from 65% of the lakes were below the threshold for issuing a fish consumption advisory.

Fish Mercury Levels in High, Medium and Low Deposition Areas Compared to the Remainder of the State



There was no obvious relationship between LMB or YP fish tissue mercury concentrations and their locations relative to prevailing wind patterns and the incinerators (see above graph of mercury in fish populations in lakes located in projected high, medium and low deposition areas in relationship to incinerators). LMB tissue concentrations correlated with the mercury content of their prey, YP, and water temperature. Tissue concentrations did not correlate with lake water pH, conductivity or dissolved oxygen concentration. The study results therefore suggest that the tissue concentrations of mercury in LMB in the study area reflect the predicted higher atmospheric mercury deposition rate for this region, which has urban and rural areas, and that these concentrations are greater than those for more rural areas of the state having lower predicted atmospheric deposition rates of mercury. Although no relationship could be discerned between the major point sources in the area and fish mercury concentrations, the resolution of the approach used (prevailing wind analysis) may have limited power to detect such effects.

Project Status: The directed study of the northeast has been completed. Several of the lakes have since been included in the long-term monitoring initiative and the seasonal variability study.

Cost: $36,000

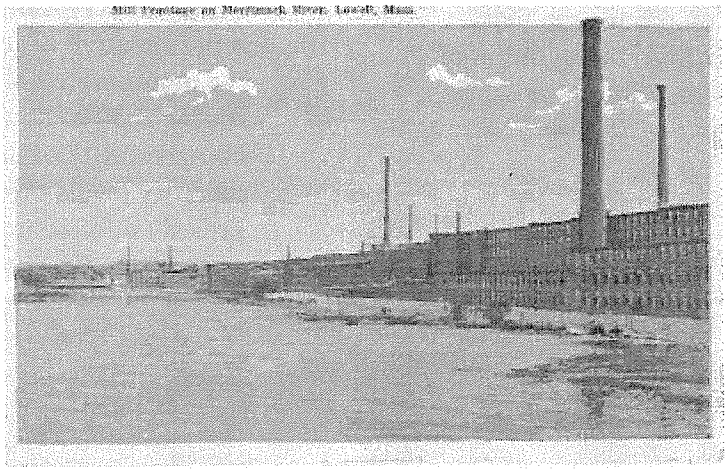
Work Products:

Reports: Fish Mercury Levels In Northeastern Massachusetts Lakes (http://www.mass.gov/dep/bwp/hgres.htm).

Publications: Field Concentrations of Fish Muscle Mercury in a Regionally High Mercury Deposition Area. Draft manuscript to be submitted to *Science of the Total Environment.*

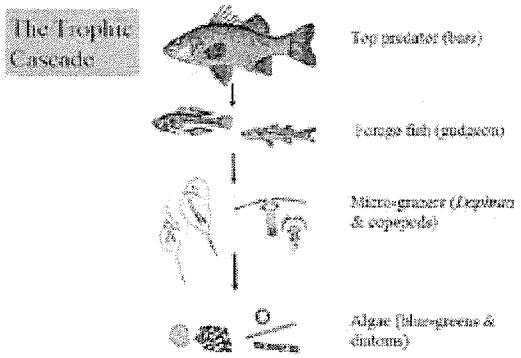
Public Presentations:

- U.S. Environmental Protection Agency, Atlantic Ecology Division, Narragansett, RI. 4/01. Invited Seminar. Mercury in Freshwater Fish in Massachusetts: Past and Future Studies.
- University of Connecticut, School of Pharmacy, Toxicology Program. Storrs, CT., 4/02. Invited Seminar. Sources of Mercury in Freshwater Fish.
- University of Massachusetts Boston, Environmental, Coastal and Ocean Studies Program. Invited Seminar. 2/03. Ecological and Land Use Perspectives in the Distribution of Mercury in Freshwater Fish in Massachusetts.
- North Atlantic Chapter of Society of Environmental Toxicology and Chemistry, Annual Meeting. 4/03. Mystic, CT. Historic Mercury Inputs and Modern Spatial Patterns in Fish Tissue Mercury Concentrations in Massachusetts.
- Northeast States for Coordinated Air Use Management, Northeast Regional Science Policy Workshop. 5/04. Kennebunkport, ME. Massachusetts Mercury Monitoring Study: Results from a Regionally High Deposition Area.
- Boston Risk Assessment Group, Northeast Chapter of Society of Risk Analysis. Boston. 7/04. Fish Tissue Mercury Concentration Trends in Northeastern Massachusetts.
- U.S. Environmental Protection Agency, Annual Regional Risk Assessors Meeting. 6/04, Boston, MA. Tissue Mercury Concentration Trends in Northeastern Massachusetts.



Title: Mercury Bioaccumulation in the Food Webs of Two Northeastern Massachusetts Freshwater Ponds.

Objectives: A food chain study was conducted of the ecosystems in two small, similar lakes located within a few miles of each other, to gain a greater understanding of the process of mercury bioaccumulation in fish, and to help determine the pathways it takes in our freshwater lakes.



Background: The recent documentation of high levels of mercury in fish from northeastern Massachusetts freshwater lakes and ponds called attention to the need for additional study of mercury bioaccumulation in these environments. Mercury is known to bioaccumulate in lake ecosystems.

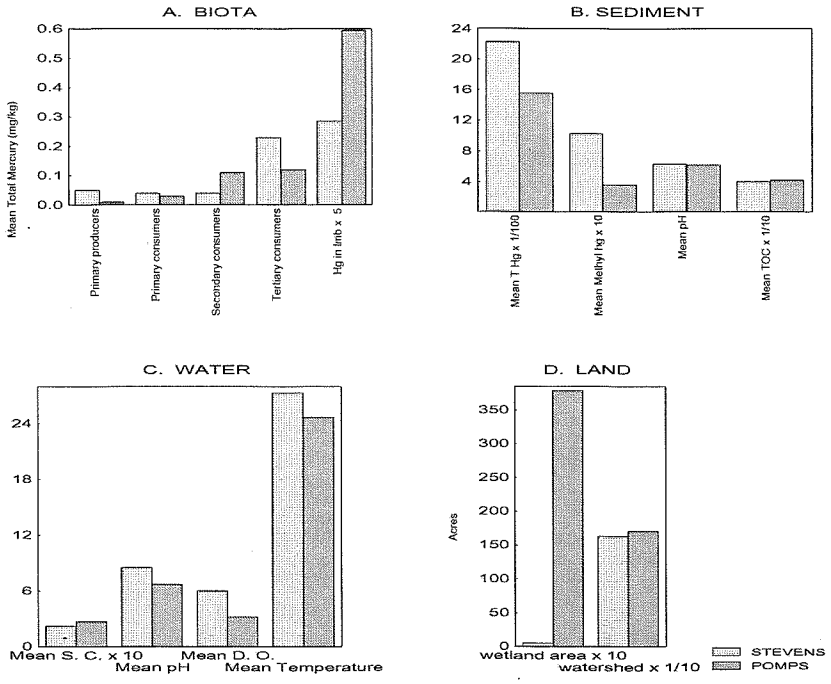
Fish studies in Massachusetts have focused on large numbers of lakes across wide geographic areas. The present study was designed to examine pond characteristics at a smaller scale, in hopes of observing relationships not perceptible in studies that encompass the variation associated with lakes in different geographic and climatic regions.

The ponds, Pomps Pond in Andover and Stevens Pond in North Andover, lie in the airshed of an urban area that conducts centralized incineration of municipal wastes. Thus, atmospheric deposition of mercury should be roughly equal into the ponds.

In a sampling event in 1999, largemouth bass from Pomps Pond contained higher amounts of tissue mercury than those from Stevens Pond. We assume that factors that influence mercury uptake in the ponds would be measurably different, since mercury concentrations in largemouth bass were different. Likewise, factors that are the same in both ponds are assumed not to have a significant influence on mercury uptake. By examining mercury content at each trophic level, we anticipated finding differences or similarities between ponds that correlated with tissue mercury concentrations in largemouth bass or other trophic groups. Ponds that bore many physical, biological and geographic similarities should increase the probability that variables favoring mercury bioaccumulation would be observable.

Study Description: Organisms representative of four trophic levels in the ponds were collected and analyzed for mercury to determine the comparability of the ponds and the mercury levels present in the ponds' broadly defined trophic niches, and sediments. Physical characteristics of the ponds including the area of wetlands in the ponds' watersheds were determined.

Partitioning of Mercury in Two Ponds



Summary of Results: The predominant measured physical difference between Stevens Pond and Pomps Pond is the area of wetlands adjacent to the ponds. The large extent of the adjacent wetlands at Pomps Pond and the near absence of wetlands at Stevens Ponds suggest that processes taking place in the wetlands may modify the partitioning of mercury in the ponds in such a way as to make it more bioavailable. Higher bioaccumulation rates in Pomps Pond may be reflective of increased mercury bioavailability due to mercury methylation within wetlands surrounding the ponds.

Project Status: Project complete. Resampling of higher trophic levels is anticipated as part of Long Term Monitoring Study.

Cost: $10,000

Work Products:

Reports: Mercury Bioaccumulation in the Food Webs of Two Northeastern Massachusetts Freshwater Ponds. MA DEP, Office of Research and Standards, 2002.

Title: Assessment of Mercury in Massachusetts Wildlife.

Objectives: A major focus of this study was to develop a comprehensive plan for further studies on mercury in Massachusetts lakes. To facilitate that goal, this study set out to collect information on mercury levels in non-fish vertebrate species of Massachusetts, and to recommend further studies that could be considered to document mercury accumulation. The study undertook a detailed literature search and compilation of information concerning mercury in non-fish vertebrates; and conducted a field survey of lakes that have habitat, food supply and other niche requirements for common loons.

Background: Studies conducted thus far show that mercury bioaccumulates in fish. Knowledge of the impact to fish-eating wildlife in Massachusetts was inadequate.

Study Description: The study compiles mercury bioaccumulation data for bald eagles, common loons, river otters, mink, voles, mice, snapping turtles and other reptiles, with bibliographies for each group. Loon surveys were conducted on several lakes, and lakes with breeding loon pairs were mapped. Additional lakes were designated likely to support loons or potentially able to support loons. Next steps for further research and biomonitoring are included.

Summary of Results: The lake survey identified many lakes capable of supporting loon populations. Detailed recommendations as to how loon populations could be established on suitable lakes by the Division of Fish and Wildlife are given in depth. Future research should:

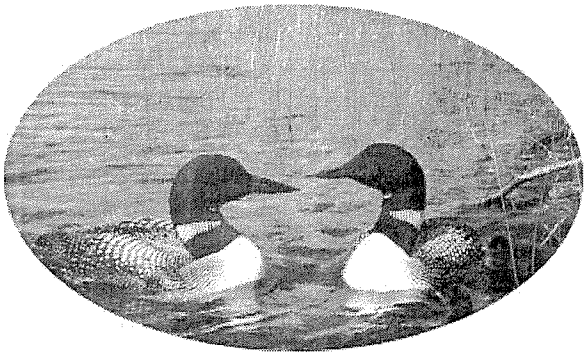
- Continue to sample bald eagle chicks annually at about 10 weeks of age;
- Continue to sample adult and chick common loons;
- Begin studies of snapping turtles.

Project Status: Project complete. The suggested next steps are under consideration for continuation. Coordination with wildlife agencies is in progress.

Cost: $14,180

Work Products:

Reports: Mercury in Non-fish Vertebrates in Massachusetts: Compilation of Existing Resources and Recommendations for the Future. Tufts School of Veterinary Medicine. Available from MA DEP ORS.



Title: Lake Sediment Mercury Deposition Study

Objectives: To determine to what extent differences in mercury fluxes to an ecosystem (in this case surface waterbodies in Massachusetts) can help explain differences in mercury concentrations in the fish residing in these systems. The specific goal of this study is to determine the feasibility of using isotope geochronological techniques to establish the recent (100 year) history of anthropogenic mercury additions to fresh water lakes in the Commonwealth.

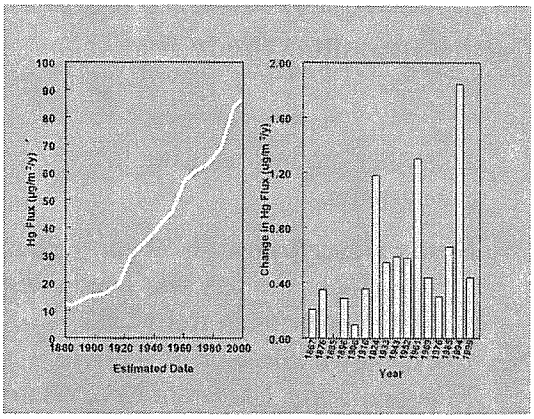
Background: Emission and deposition rates of mercury can be quite variable, with depositional rates of mercury in a local region dependent on both distant and local emission sources, and regional and local atmospheric transport. Most of the supply of mercury to freshwater systems is thought to be derived from atmospheric input, because the retention of mercury in most watersheds surrounding such systems is extremely efficient (>90% retention).

By comparing mass flux rates of mercury to different lakes and ponds it may be possible to better understand both local and regional heterogeneity of primarily atmospheric mercury fluxes to such systems and determine the linkage, if any, to local and regional heterogeneity in fish body burdens of mercury. The information provided by this approach can be used to both validate atmospheric models predicting mercury transport and deposition as well as contribute to the primary goal of understanding the environmental variables influencing mercury concentrations in tissues of fish and other organisms using these ecosystems.

Study Description: Isotope (^{210}Pb and ^{137}Cs) geochronology was used to date a sediment core taken from Lake Cochichewick in North Andover, Massachusetts, known to have relatively high mercury concentration in fish resident in the lake. Historical changes in mercury contamination of the lake were determined using the mass accumulation rates determined by isotope geochronology and measurement of mercury concentrations downcore.

Summary of Results: The data clearly show a low and slowly increasing concentration of mercury before the 1900s and then a rapid increase in concentration beginning in the late 1800s and early 1900s. Concentrations are highest at the top of the core and are over an order of magnitude higher than those observed in the deeper part of the core that are more characteristic of relatively pristine areas (~20 - 30 ng/g dry weight). However, the uppermost section of the core analyzed in this work represents a time period of about 4 years or the period from 1997 to the date of collection in May 2001. Lack of temporal resolution at the surface of the core may mask any decrease in concentration occurring over the last few years.

The highest single increase was observed for the core section representing the period between 1990 and 1996, shortly after the construction of the incinerators in the 1980s near Lake Cochichewick. Whether



Mercury fluxes into sediments of Lake Cochichewick over the last 120 years. Panel on right indicates estimated change in sediment flux for each dated core section.
Note the absence of any decrease in mercury concentration over the last decade.

this jump in Hg flux was wholly in response to the emissions from these incinerators cannot be conclusively determined by the limited data from a single sediment core, but does argue for closer scrutiny of the importance of these and possibly other local and regional sources.

Project Status: Project complete. Additional lake sediment cores are planned at strategically located lakes, and fish sampling and analysis has been conducted in lakes where sediment cores have been obtained.

Cost: $18,000

Work Products:

Reports: Determination of Recent Inputs of Mercury to Lakes/Ponds in the Merrimack Valley Using Sediment Cores – A Feasibility Study, by G. Wallace, S. Oktay, F. Pala, M. Ferraro, M. Gnatek, & D. Luce. Dept. of Environmental, Coastal and Ocean Sciences, U Mass Boston, Boston, MA.

Publications: Manuscript in preparation.

Public Presentations:

- University of Massachusetts Boston, Environmental, Coastal and Ocean Studies Program. Invited Seminar. 2/03. Ecological and Land Use Perspectives in the Distribution of Mercury in Freshwater Fish in Massachusetts.
- North Atlantic Chapter of Society of Environmental Toxicology and Chemistry, Annual Meeting. 4/03. Mystic, CT. Historic Mercury Inputs and Modern Spatial Patterns in Fish Tissue Mercury Concentrations in Massachusetts.
- Northeast States for Coordinated Air Use Management, Northeast Regional Science Policy Workshop. 5/04. Kennebunkport, ME. Massachusetts Mercury Monitoring Study: Results from a Regionally High Deposition Area.
- Boston Risk Assessment Group/Northeast Chapter of Society of Risk Analysis. Boston. 7/04. Fish Tissue Mercury Concentration Trends in Northeastern Massachusetts.

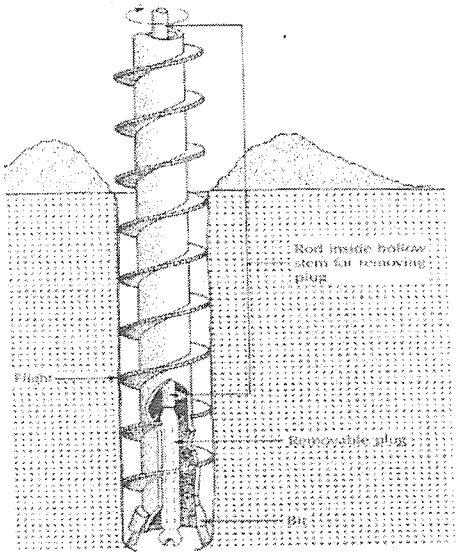
Title: Sediment Coring Workshop

Objectives: A one-day workshop was convened, attended by regional scholars in sediment geochemistry and the ORS staff, to:

- Solicit input from the research community on the geochemical factors that may influence the flux of mercury into ponds within the Commonwealth of Massachusetts;
- Investigate a range of dating techniques used in coring;
- Become familiar with problems encountered in sediment core analysis and interpretation;
- Receive expert advice on the value and effectiveness of a sediment coring program for evaluating mercury deposition in Massachusetts lakes;
- Compare costs of sediment coring programs.

Background: The MADEP completed two major investigations of mercury in freshwater fish in ponds in the Commonwealth. Based on the results of the investigations on mercury in freshwaters performed to date, the MADEP proposed that a sediment coring program be developed and implemented in order to:

1) Further develop a historical perspective on mercury inputs in freshwater environments,
2) Differentiate between local and regional sources of mercury,
3) Evaluate the variation in mercury concentrations between different waterbodies and aquatic organisms, and
4) Establish a long term monitoring program.



Study Description: The workshop consisted of summary presentations of the mercury investigations that have been sponsored by MA DEP, presentations of the invitees, and findings of their research. Directed discussions for the remainder of the day included experiences with sediment coring, the laboratory analysis of sediment samples and data analysis and interpretation. The purpose of the workshop discussion session was to discuss any practical concerns for the

planning and implementation of future sediment coring programs. Presenters from the research community were:

Dr. Gordon Wallace – University of Massachusetts at Boston;

Dr. Tim Parshall – Harvard Forest, Harvard University;

Dr. Gabe Benoit – Yale School of Forestry and Environmental Studies;

Dr. John Colman – United States Geological Survey.

Summary of Results: Following the review of the recommendations made during the workshop a Work Plan for the Sediment Coring Program was to be prepared. A solicitation would then be issued for sampling and analytical services to support the Sediment Coring Program. The timing of the issuance of any Request for Proposals (RFPs) and the implementation of the proposed Sediment Coring Program would be dependent upon the availability of funding for the study by the Commonwealth with the potential for joint funding with other institutions and agencies.

Project Status: Workshop completed. Additional lakes are being investigated as potential candidate lakes for coring.

Cost: $3,500

Work Products:

- Improved knowledge of the use of sediment coring for analysis of mercury deposition.
- Improved contacts with regional experts in the field.

Reports:

Sediment Coring Workshop, June 26, 2001, Tower Hill Botanical Garden, Boylston, Massachusetts, Letter Report to MA DEP, Office of Research and Standards. Normandeau Associates.

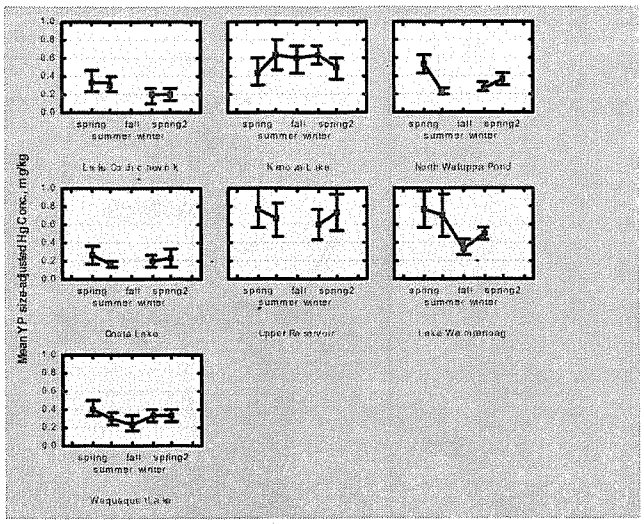
Title: Fish Mercury Seasonal Variability Study

Objectives: The objectives of this study were to document the concentrations of fish tissue mercury in each of the major seasons and determine if and how they vary from season to season. The knowledge gained from this project is intended to tell us whether time of year is a critical variable to be factored into planning future fish sampling efforts.

Background: Massachusetts has been monitoring the concentrations of mercury in fish tissue throughout the state for approximately 20 years. The primary goal of much of this work has been to identify fish populations that might pose unacceptable health risks to those consuming the fish. Sampling sites have not often been revisited in subsequent years and until the late 1980's, methods and procedures were not fully standardized, and sampling intensity was not designed to permit rigorous comparisons of between-year trends. A long term monitoring plan was devised to address this problem. During the initial sampling years of the long term monitoring study described later, a study of seasonal variation in fish tissue mercury was conducted.

Study Description: LMB and YP were sampled and analyzed for mercury at 7 of the long-term study lakes. Sampling times were spring (pre- and post-spawn), summer, autumn, winter and spring again. (pre-and post-spawn).

Summary of Results: Maximum seasonal differences between YP edible muscle tissue mercury concentration means for a lake ranged from 20 to 112% and LMB mean differences ranged from 26 to 107%. Values were generally highest in the spring. The substantial variation in the raw data means suggests that seasonal variation may be an important source of variation in fish tissue mercury data sets that should be considered in the design or interpretation of these types of data sets.



Seasonal Mean Size-Adjusted Tissue Mercury Concentrations (mg/kg) in Yellow Perch

Project Status: Field and laboratory work complete. Draft report complete.

Cost: $73,000

Work Products:

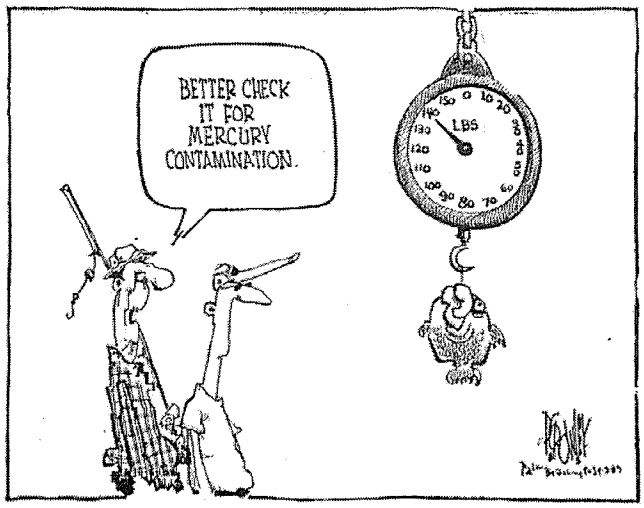
Reports: Preliminary Study Summary - Long-term Monitoring Program of Fish Mercury in Massachusetts Lakes and Study of Seasonal Variation in Fish Mercury, Section A-"Fish Mercury

Studies: Long-term Monitoring Program and Directed Studies 2001-2003. MA DEP, Office of Research and Standards, 2004.

Publications: Manuscript in preparation.

Public Presentations: Sources Of Variation In Fish Tissue Mercury Concentration Estimates And Suggestions For Study Design And Data Interpretation Improvement North Atlantic SETAC Meeting Poster, 2004.

University of Massachusetts Boston, Environmental, Coastal and Ocean Studies Program. Invited Seminar. 2/03. Ecological and Land Use Perspectives in the Distribution of Mercury in Freshwater Fish in Massachusetts.



Title: Examining Laboratory Methods to Reduce Variability and Facilitate Reporting Results

Objectives: This study was designed to assess whether mean tissue mercury concentrations variance estimates could be reduced by reporting data on a dry weight basis rather than a wet weight basis. Analysis of fish mercury within specific holding time is mandated by US EPA, and the time limits sometimes have not been met or met with difficulty. We therefore sought to determine the stability of mercury in frozen freshwater fish muscle samples over time, in order to justify analyzing samples after holding them longer than the mandated holding times.

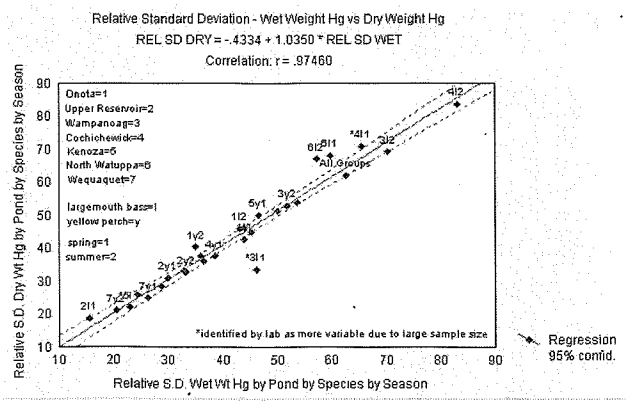
Background: Given the large seasonal changes in the condition of fish associated with their seasonal reproductive cycle, we hypothesized that the degree of tissue hydration could change seasonally and that apparent variation in wet weight-expressed tissue mercury concentrations could be due in part to varying water contents, or else differential loss of adhering moisture during processing of tissue samples.

US EPA mandates most holding times for analytes in order to maintain the integrity of the analyte of interest. The US EPA recommends a holding time of 28 days for mercury analysis of frozen fish tissue homogenates. We sought to document what happens to the mercury concentrations after 28 days, to provide a basis for delayed analysis. This provides the laboratory with more flexibility in scheduling the work load.

Study Description: For the tissue moisture content study, we determined total mercury concentrations expressed on a wet weight basis on large numbers of edible muscle tissue from largemouth bass and yellow perch from 7 lakes in Massachusetts, sampled in the spring and summer. Subsamples of the same tissues were weighed wet, dried overnight at 60°C and their dry weights determined. The moisture contents of these tissues were then used to adjust the wet weight Hg concentrations to a dry weight basis. The wet weight values were used to calculate means, standard deviations and coefficients of variation for groups of tissues. The same statistics were calculated for the dry weight basis values.

For the holding time study, we tested archived frozen fish tissue homogenates within the holding time, after two months and after one year.

Summary of Results: Expressing tissue mercury concentrations on a dry weight basis does not provide any reduction in sample variance estimates in largemouth bass and yellow perch.



With regard to mercury analysis variation associated with different holding times, insignificant variation in mercury levels occurred after two months. After one year, the mercury content of approximately 50% of the samples decreased significantly.

Project Status: The tissue moisture content study is complete. Wet weight measurements are now standard operating procedure. The holding time study will be repeated using larger sample sizes.

Cost: This work was conducted by personnel at Wall Experiment Station, and was supported with funds for the seasonal variability study.

Work Products: The tissue moisture study results have been incorporated into laboratory standard operating procedure. Modification of the laboratory standard operating procedure for mercury analyses to recognize holding times for up to 60 days for research projects is provisionally incorporated into laboratory standard operating procedure for research projects. The standard US EPA 28 day holding time will continue to be observed for enforcement sensitive or public health advisory related work.

Public Presentations:

Sources Of Variation In Fish Tissue Mercury Concentration - Estimates And Suggestions For Study Design And Data Interpretation Improvement. North Atlantic SETAC Meeting Poster, 2004.

Boston Risk Assessment Group, Northeast Chapter of Society of Risk Analysis. Boston. 7/04. Fish Tissue Mercury Concentration Trends in Northeastern Massachusetts.

Title: Long Term Monitoring Program for Fish Tissue Mercury Trends

Objectives: A program to monitor fish mercury in selected lakes was initiated to determine whether the levels of mercury in fish are decreasing over time as a result of increased controls on mercury emissions sources; and, to sample waterbodies on a cyclic basis to identify other trends in fish mercury bioaccumulation.

Background: Early studies of fish tissue mercury in Massachusetts were conducted to provide broad or local spatial assessment of the need for fish consumption advisories. Locations were seldom revisited. As both the fish mercury work intensified and the state pressed for tighter controls on mercury emissions and sought to reduce mercury use in the Commonwealth, the need for a program to document long-term trends in fish tissue mercury concentrations became apparent.

Study Description: Beginning in 2001, the Office of Research and Standards selected 18 permanent locations for fish tissue mercury monitoring in Massachusetts to provide vital information to help understand fish mercury dynamics (Appendix 1). This information would provide a consistent, long-term record of mercury concentrations in fish across the state. The data would represent an indicator of the responses of the environment to changes in mercury inputs as a result of mercury emissions control efforts. The information on year-to-year variation in fish mercury concentrations could be determined using long term data. In cases where data collected in different years are compared to evaluate the influence of some other variable (e.g., urban versus rural comparisons), knowledge of the magnitude of inter-annual variation would assist with the determination of the significance of differences attributed initially to other factors. Half of the lakes are sampled every year, so that data will be available for any particular lake every other year.

Summary of Results: Preliminary analysis of year-to-year temporal trends in fish mercury concentrations for lakes in northeastern MA has indicated that there have been statistically significant decreases in tissue mercury concentrations in both LMB and YP from 1999 through 2004.

Project Status: Data collection and analysis is ongoing. Two additional lakes in the northeast have been added to the original list of lakes to provide a more detailed picture of longer-term temporal trends in the Merrimack River Valley, where substantial reductions in atmospheric emissions of mercury have come to pass over the last few years. Other lakes were added from two areas of particular interest: Echo Lake in Hopkinton, where a dated record of mercury from sediment coring of this rural lake exists; and the Quabbin Reservoir, where atmospheric mercury deposition measurements have been made.

Cost: $68,500 for 2004.

Work Products:

Reports:

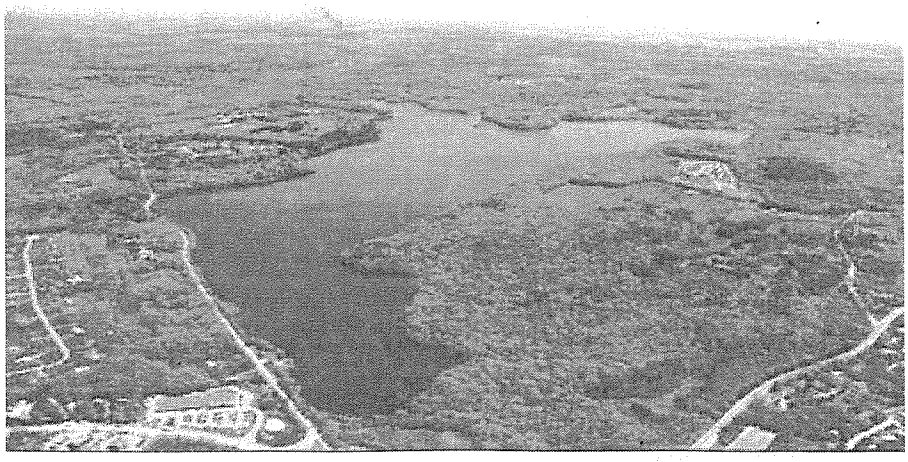
- Fish Mercury Studies Status Report to March 31, 2004.
- Draft Final Report. Massachusetts Fish Tissue Mercury Studies: Long-Term Monitoring Results 1999 – 2004. MA DEP, Office of Research and Standards, (report in preparation).

Publications: Manuscript in preparation.

Public Presentations:

- Northeast States for Coordinated Air Use Management, Northeast Regional Science Policy Workshop. 5/04. Kennebunkport, ME. Massachusetts Mercury Monitoring Study: Results from a Regionally High Deposition Area.
- Boston Risk Assessment Group/Northeast Chapter of Society of Risk Analysis. Boston. 7/04. Fish Tissue Mercury Concentration Trends in Northeastern Massachusetts.
- Annual Meeting European SETAC. 5/05. Lille, France. Temporal Responses of Fish Tissue Mercury Concentration Responses to Local Atmospheric Mercury Emissions Reductions from Incinerators.

Lake Cochichewick, North Andover, with Municipal Waste Combustor in the Background



Title: Sources Of Variation In Fish Tissue Mercury Concentration - Suggestions For Study Design And Data Interpretation Improvement

Objectives: Assemble the information we have learned concerning sources of variation in fish studies in one place, to show how to improve the efficiencies of fish tissue mercury sampling programs. Knowledge of the major sources of variance in the data can be helpful and used to improve the precision of fish tissue mercury predictions in waterbodies by lowering the variance where possible.

Background: The objective of many studies of edible fish tissue mercury concentrations is to provide estimates of lake population mean mercury concentrations for comparison with human health or ecologically-based tissue concentration exposure limits or to compare between different sample groups. Insufficient attention may be given to the inherent variability in fish tissue mercury concentrations in the design of studies and during the interpretative phase of studies. The implications of conclusions reached or actions taken based upon false positives or negatives from such studies may have substantial public health and ecological consequences (e.g., unnecessary closure of a fishery or failure to protect public health with a warranted fish consumption advisory or to detect an ecological threat).

$$\sigma_x^2 = \frac{1}{N-1}\sum_i \left(x_i - \bar{x}\right)^2$$

Study Description: This work component takes information gathered from the various Mercury Initiative sponsored projects and summarizes it in a practical format which can be used by others in the future to improve study designs and the quality of data interpretation. Sources of variation in fish tissue mercury concentrations which are considered include the correlation of mercury with fish size, the season in which the fish were collected, the degree of tissue hydration, the reproductive status of fish, and calculation of sample sizes.

σ	Power
50	.52
75	.26
100	.17
125	.12
150	.10

Summary of Results: The following recommendations have come out of our studies and experiences:

- perform analyses on individual fish using statistically based numbers of fish in order to preserve variance information and provide sufficient confidence and power in the study design;
- look for mercury concentration – size relationships and adjust for this covariate if necessary, using ANCOVA or size-standardization;
- try and obtain comparison samples (temporal or spatial) at the same time of year. Aggregated tissue mean mercury concentrations

calculated over seasons will have higher variance than same season means, and

- depending on the intended use of the data, recognize that spring samples of yellow perch and largemouth bass will give the highest estimate of population mercury concentrations.

Projected Status: Work in progress.

Cost: NA

Work Products:

Publications: Manuscript for peer review publication planned.

Public Presentations:

"Sources of Variation In Fish Tissue Mercury Concentration Estimates And Suggestions For Study Design And Data Interpretation Improvement." – poster presentations at:

- North Atlantic Chapter of the Society of Environmental Toxicology and Chemistry, Annual Meeting. 4/03. Mystic, CT.
- Boston Risk Assessment Group/Northeast Chapter of Society of Risk Analysis. Boston. 7/04.

Appendix 1. Waterbodies for Long-term Monitoring

Waterbody	Years Sampled	Acres	Town	PALIS #
Onota Lake	1976 2001-2002 2004	617	Pittsfield	21078
Lake Wampanoag	1995 2001-2002 2004	218	Ashburnham Gardner	81151
Upper Reservoir	1995 2001-2002 2004	57	Westminster	35091
North Watuppa Pond	1995 2001-2002 2004	1700	Fall River	61004
Wequaquet	2001-2002 2004	654	Barnstable	96333
Lake Cochichewick	1999 2001-2002 2004	555	North Andover	84008
Kenoza Lake	1998 1999 2001-2002 2004	287	Haverhill	84028
Lake Lashaway	1994 2003	270	North & East Brookfield	36079
Wickaboag Pond	1995 2003	320	West Brookfield	36166
Lake Nippenicket	1978 2003	354	Bridgewater	62131
Massapoag Lake	1979 2003	353	Sharon	73030
Haggetts Pond	1999 2003	214	Andover	84022
Buckley-Dunton Reservoir	1995 2003	195	Becket	32013
Lake Saltonstall	1999 2003	45	Haverill	84059
Baldpate Pond	1999 2004	55	Boxford	91001
Chadwicks Pond	1999 2004	161	Haverhill/Boxford	84006
Echo Lake	2004	123	Milford/ Hopkinton	72035
Quabbin Reservoir	1989 2004	25,000	Petersham, New Salem, Ware, Belchertown, Pelham, Hardwick, Shutesbury	36129